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The Dynamic Measurement and Conservative Treatment of Thoracic Hyperkyphosis

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Date of submission
April 2011

A thesis submitted for the degree of

Doctor of Philosophy

of

The Australian National University

I, Diana Margaret Perriman, hereby declare that this submission is my own work and that it contains no material previously published or written by another person except where acknowledged in the text. Nor does it contain material that has been accepted for the award of another degree or diploma in any university.

In addition, ethical approval from the ACT Health Human Research Ethics Committee and the Australian National University Human Research Ethics Committee was granted for the studies presented in this thesis. Subjects were required to read a subject information document and informed consent was gained prior to data collection.

Diana

Signed, Diana Margaret Perriman

Date 24/10/11

As supervisor of Diana Periman's doctoral work, I certify that I consider her thesis "The Dynamic Measurement and Conservative Treatment of Thoracic Hyperkyphosis" to be suitable for examination.

Signed P Smith

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ACKNOWLEDGEMENTS

This PhD thesis is the result of a lot of work but not just mine. I have had to call upon the knowledge and experience of a myriad of remarkable people who have astonished me with their generosity and kindness. Of course everyone who makes this journey always thanks their spouse/family for supporting them through the marathon journey of a PhD. I must, however, thank my husband, Christian, for that and for so much more. He has been both friend and mentor throughout. He has steadfastly tolerated my absences and my many frustrations. Miraculously we remain happily married and our two daughters, Suzie and Freya, are still happy and well adjusted. Thank you from the bottom of my heart and the depths of my soul for your patience and perseverance.

Now to the myriad of others who deserve a place in this work.

First, my supervisors and advisors

A/Prof Paul Smith is a very busy man. He juggles an enormous clinical practice while at the same time making time for the likes of me. I am so humbled to have been given so much of his valuable time and so very grateful for all the support and wisdom he has offered me. He is a powerful force for good and uses his considerable intellect, charisma and energy to make so much happen. Thank you Paul. You are amazing.

Dr Jennie Scarvell is one the Australian National University's top supervisors, and deservedly so. Nothing is ever too much trouble for Jennie. Being one of her students is like winning the lottery. I cannot imagine having completed this thesis without the painstaking care that Jennie has taken to nurture and guide me through every step of the process. Jennie, you are one of nature's gems.

Dr Andrew Hughes was instrumental in securing the funding for me to conduct the studies described in this thesis. Without him I could not have done anything. He has helped and advised me with the manuscript and study design and offered thorough and good hearted advice throughout the very long course of this project; thank you Andrew for your humour, patience and generosity.

Dr Teresa Neeman is quite simply the most charming statistician I have ever met. She has a great gift for teaching and I so much enjoyed all of our many sessions. Thank you Terry, the veil has fallen and I am a true convert to the elegance of statistics.

Dr Keith Dear was instrumental in formulating my experimental design and taught me to use Stata. Thank you Keith.

Dr Bryan Ashman is another busy surgeon who generously assisted me with my early validation experiments and gave me the confidence to believe in myself in the field of spinal science. Bryan, I am in your debt.

Dr Anna Cowan is the vice dean of the ANU medical school and was on my supervisory panel. Although we did not meet up very much, when we did she could not have been more helpful or supportive. Thank you Anna.

Dr Eddie O'Brien is the sort of friend that everyone needs and I am so lucky to have. He was my statistics and mathematics advisor before I had one and is the one I went to with questions that I was just too embarrassed to ask anyone else – he, of course, knew the answers. Eddie, you are one in a million.

Second, the granting bodies who generously funded the studies described in this thesis.

The **NH&MRC** awarded me a Dora Lush scholarship for which I am very grateful.

The **Canberra Hospital Private Practice Fund** provided me with a very generous grant which paid for the bulk of the costs of running the studies.

AO Spine provided me with a grant for some of the equipment used in the validation studies.

Third, the people who offered me particular assistance with the individual thesis sections.

Many of the people who were mentioned above were involved in the design and execution of the studies described in this thesis and/or the writing of it. Others who must be acknowledged are:-

Prof Mark Pearcy (Queensland University of Technology) for early advice on the validation experiments (chapter 3). Jo Rivera (Radiology, the Canberra Hospital) for advice and assistance with the validation experiment (chapter 3). Stephanie Poustie (the Department of Epidemiology and Preventative Medicine, Monash University) for advice and assistance with the survey design (chapter 4). A/Prof Mark Pickering (University of NSW at ADFA) and Dr Nick Ball (Faculty of Health and Sports Science at the University of Canberra) for advice and assistance with the sEMG experiments (chapters 5 and 7). Maurice Sommariva (Biomedical Engineering the Canberra Hospital) for making the wall mounting for the myometer used in chapters 5,6,7,8 and 9 and the adaptation to the back machines used in the RCT (chapter 9). Prof Gordon Waddington (University of Canberra), Prof Graeme Buirski (Radiology, the Canberra Hospital) and Ms Annette Lawson (National Capital Diagnostic Imaging) for advice and assistance with the ultrasound study (chapter 6). Mr Peter Makeham (mechanical engineer), Dr Nick Brown (Biomechanist, Australian Institute of Sport) and Dr Tom Ward (Bioengineer, The Canberra Hospital) for advice and assistance with the kinematic studies (chapter 7). Tim Maher (tm Physio), Liz Abbott (Woden Integrated Physiotherapy) and Christine O'Brien (University of Canberra and Calvary Hospital) for providing the postural re-education interventions for the RCT (chapter 9). Also Leonard Duca from the ANU Sport and Recreation Association Inc and Rhys Cutifani from the Southern Cross Health Club for generously making their facilities available to the subjects who participated in the RCT.

Fourth, the people in the background who so generously dealt with all the practical problems for me.

All the staff at 'TheTrauma and Orthopaedic Research Unit' (TORU). Thank you, especially Roxanne Miller, who was my trusty right hand girl and a treasured friend. Also my fellow PhD students Angie Fearon, Susannah Littleton, Jon Slater and Ben Serpell - thank goodness I had someone with whom to share the ups and downs. Also huge thanks to Kylie McKay, A/Prof.Rachel Li, Jane Wilson, Laura Gladkis, Camilla Smith and Liz Bennett for all their assistance and advice.

The Australian National University is a fantastic university. I cannot imagine another which could, or would, so willingly provide their postgraduate students with so much information, education and support from beginning to end. The information literacy programme is superb as is the Research Student Development Centre. I would like to single out Dr Wei Shi who is a brilliant and helpful administrator; Hans Joerg Kraus who held my hand through the nerve-wracking business of formatting and putting my document together, and Vojislav Zeljkovic, Ricardo Gallardo and Sinisa Nesic in the IT support unit. You have all been a wonderful resource. I am so grateful.

The Canberra Hospital has been my home for the duration of my studies and my grant monies have been managed by two wonderful accountants, Regan Freeburn and Claire Farr. They have gone out of their way to make my life as easy as possible. I was also fortunate to discover an extraordinary librarian, Linda Heslop, who I have recommended to all. In medical records Gloria Spyropoulos is a lady who is known and loved by all, especially me.

Last, but definitely not least, my participants.

Without you there would be no data to report. I cannot list you of course, but your spirit and generosity resonates in the pages of this thesis. I have often heard it said that Canberra is a kind of nirvāna for the researcher because the people are so willing to give of themselves for the sake of furthering knowledge. I can certainly attest to their generosity. Thank you all so very much.

DEDICATION

For Christian Joseph Lueck, Suzanna Allegra Perriman Lueck, Freya Maddalena Perriman Lueck, Anthony Bruce Perriman and Marie Elizabeth Perriman, with love and gratitude.

Science is about discovery but it is also about creativity. Nobel prize winner Albert Szent-Györgyi de Nagyrápolt said *"Creativity is to see what everybody else has seen, and to think what nobody else has thought"*.

ABSTRACT

Age-related hyperkyphosis of the thoracic spine is a problem which potentially affects all adults. It can result in movement dysfunction and may lead to mechanical failure of the thoracic spine, especially in the presence of osteoporosis, due to overwhelming forces exerted by gravity and muscular contraction. A number of studies have endeavoured to evaluate exercise-based programmes aimed at reducing hyperkyphosis in older adults. However, the multimodal nature of these programmes may reflect the uncertainty about which strategies are most effective.

Stroke is a condition which affects 322 000 people in Australia at any given time. Rehabilitation strategies for stroke have commonly excluded resisted strengthening strategies because of fears of increasing spasticity. However, recent studies have failed to confirm this concern. Loss of back extensor strength (BES) is a feature of stroke which is detrimental to function. The effect of resisted BES exercise on function in people with stroke has not been examined.

This thesis describes a number of studies that each inform the design and execution of a randomised controlled trial (RCT) which aimed to establish the relative effectiveness of BES exercises and postural re-education in reducing hyperkyphosis. The preliminary studies included three experiments validating the flexible electrogoniometer (FEG) as a tool to measure thoracic kyphosis, a survey looking at the normal practice of Australian physiotherapists with respect to thoracic hyperkyphosis; three experiments using surface electromyography (sEMG), kinematic and force measurements to determine whether sitting or prone lying was a better exercise positions for strengthening the thoracic erector spinae (TES); an ultrasound study looking at the anatomy of two sEMG recording sites; and a study validating the myometry used in the RCT.

The three FEG validation studies included: a bench test for accuracy, a test-retest reliability study and a study of concurrent validity comparing FEG angle to corresponding Cobb angles. The studies indicated that the FEG is a reliable instrument with excellent day-to-day reliability ($ICC_{2,1} = 0.92$; $p < 0.0001$). When compared with the Cobb angle for concurrent validity, the FEG was found to have

the best agreement with the Cobb angle for the section of spine between mid end-blocks ($r = 0.814 – 0.821$, $p = 0.001$) with an absolute difference of 3.5°± 6.9°.

A stratified cross-sectional mailed survey was used to examine how Australian physiotherapists from varying practice groups assess and manage hyperkyphosis. It revealed that postural re-education, stretching and strengthening were the interventions most frequently used to treat thoracic kyphosis but that the measurement tools used to evaluate treatment effectiveness were primarily subjective.

A prospective observational study which used real time ultrasound to image the muscles overlying the erector spinae at T3 and L4 established that the thoracic erector spinae (TES) could not be accurately recorded with sEMG. Therefore, a comparative analysis of the relative contributions of the TES and lumbar erector spinae (LES) was achieved by comparing the forces developed during prone and seated extension and the levels of LES activation. The results indicated that the TES were recruited to a greater extent during seated extension with scapular retraction than they were during prone extension. In addition, a kinematic study comparing the two exercises showed that prone extension primarily resulted in hyperextension of the lumbar spine with limited thoracic extension.

A test-retest study of a seated myometry method for testing BES showed that it had excellent day-to day reliability ($ICC_{2,1} = 0.96$ (95% CI 0.83 – 0.99)). The minimum difference needed to detect a real difference in force generated between measurements (MD) was 20.7N for extension with retraction.

The RCT was subject blinded and utilised a 2X2 factorial design to compare the effects of postural re-education and strengthening. Both stroke and non-stroke (normal) subjects were included although the majority of the subjects were normal. The results of the RCT indicated that, overall, the strengthening intervention resulted in better outcomes in terms of physical ability but that there was no significant reduction in kyphotic angle. The results also suggest that the angular changes which did occur mainly occurred in the upper thoracic spine. Thoracic spine movement frequency was found to be very low in both the sagittal (0.001Hz)

and coronal (0.002 Hz) planes which may have implications for the nutrition of the intervertebral disc. There were no differences between the stroke and non-stroke cohorts in terms of their responses to the intervention.

The main clinical significance of this work is the discovery that an increase in back extensor strength does not necessarily result in a clinically significant decrease in thoracic kyphosis, especially at the apex of the curve. Further research is required to explore the best conditions in terms of load and position for thoracic extension strengthening for decreasing kyphosis. The effect of intervention on movement frequency is potentially an area of significant interest with respect to reducing the rate of disc disease.

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NOMENCLATURE

Term	**Meaning**
Aponeurotic	Pertaining to the muscle aponeurosis
Cobb Angle	The angle of curvature made by the curve of the thoracic spine measured from a lateral X-ray
Hyperkyphosis	Excessive kyphosis (see below)
Kyphosis	The direction of curvature of the spine where the anterior aspect is concave.
Kyphotic angle	The angle made by the curve of the thoracic spine
Myometry	Muscle strength testing
End block	Terminal endings of the FEG which attach to the skin
Marginal Mean	The mean response for a factor averaged across all levels of another factor or factors (statistics).

Acronym	**Meaning**
1RM	The maximum amount of weight able to be lifted or moved in a single repetition for a given exercise
ANU	Australian National University
BES	Back Extensor Strength
BMD	Bone Mineral Density
BMI	Body Mass Index
EMG	Electromyography
EO	External Oblique muscle
ES	Erector Spinae
FEG	Flexible Electrogoniometer
FHP	Forward Head Posture
ICC	Intra-class Correlation Co-efficient
KI	Kyphotic Index
L1 – L5	Lumbar vertebrae from the first to the fifth
LES	Lumbar Erector Spinae

NOMENCLATURE CONTINUED

LSD	Least Significant Difference
MVIC	Maximum Voluntary Isometric Contraction
nEMG	Needle Electromyography
PA	Posterior to Anterior direction
RCT	Randomised controlled trial
RMS	Root Mean Square
ROM	Range Of Movement
SD	Standard Deviation
SE	Standard Error of the Mean
sEMG	Surface Electromyography
T1 – T12	Thoracic vertebrae from the first to the twelfth
TCH	The Canberra Hospital
TES	Thoracic Erector Spinae
TLF	Thoraco-Lumbar Fascia
TORU	Trauma and Orthopaedic Research Unit
US	Ultrasound

PUBLICATIONS

1. Perriman, D.M., Scarvell, J.M., Hughes, A.R., Ashman, B., Lueck, C.J. and Smith, P.N. *Validation of the flexible electrogoniometer for measuring thoracic kyphosis.* Spine (Phila Pa 1976), 2010. **35**(14): p. E633-40.

2. Perriman, D.M., Scarvell, J.M., Waddington, G.S., Lueck, C.J., Hughes, A.R., Neeman, T.M.and Smith, P.N. *Ultrasound assessment of the anatomical validity of T3 and L4 as sEMG recording sites.* Journal of Biomechanics, 2011. **44**: p. 1025 - 1030.

PUBLISHED ABSTRACTS

Perriman, D.M. Scarvell, J.M. Hughes, A.R. Lueck, C.J. Ashman, B. Smith, P.N. (2008): Measurement of Flexion and Extension of the thoracic Spine with the Flexible Electrogoniometer: In *Proceedings of the 68th Australian Orthopaedic Association Annual Scientific Meeting*, Hobart.

Perriman, D.M. Ashman, B, Scarvell, J.M., Hughes, A.R. Lueck, C.J., Smith, P.N (2009): Measurement of Flexion and Extension of the thoracic Spine with the Flexible Electrogoniometer: In *Proceedings of AO Spine Global Spine Congress*, San Francisco.

Perriman, D.M. Ashman, B. Scarvell, J.M. Hughes, A.R. Lueck, C.J. Smith, P.N (2009): Which is the Best Exercise to Train Thoracic Erector Spinae? A Surface EMG Study (Poster presentation): In *Proceedings of AO Spine Global Spine Congress*, San Francisco.

Perriman, D.M. Scarvell, J.M. Hughes, A.R. Lueck, C.J. Smith, P.N. (2009): Thoracic kyphosis: A survey of Australian physiotherapists: In *Proceedings of the Australian Physiotherapy Association National Conference*: Sydney.

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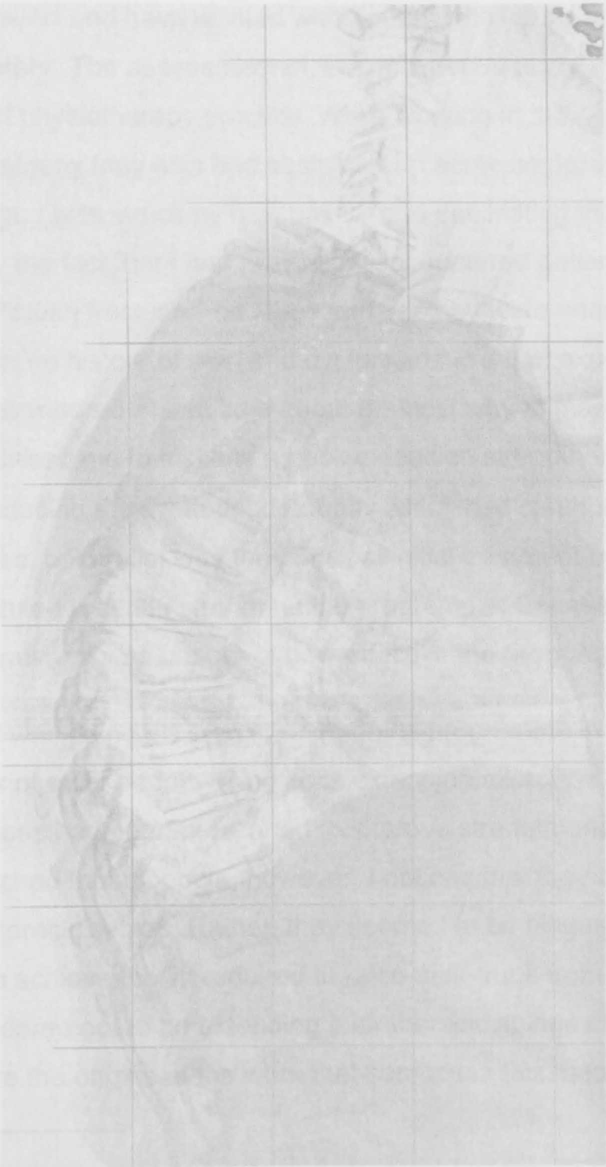
Perriman, D.M. Scarvell, J.M. Waddington, G. Lueck, C.J. Neeman, T.M. Hughes, A.R. Smith, P.N. (2010): Ultrasound evaluation of thoracic and lumbar erector spinae surface EMG recording sites: In *Proceedings of the Asics Conference of Science and Medicine in Sport*, Port Douglas.

Chapter 1.

Introduction



1.1. Background

The broad aim of this thesis was to investigate some of the underlying assumptions which underpin the conservative treatment of age-related hyperkyphosis of the thoracic spine. More specifically the main aim was to examine the relative efficacy of the most commonly used conservative treatment strategies for reducing age-related hyperkyphosis*.

I am a physiotherapist and have worked with adults, both young and old, throughout my career. The assessment of, and instruction about, good posture, are central features of physiotherapy practice. While working in the community I was once referred an elderly lady who had sustained an acute compression fracture of a thoracic vertebra. I was struck by how painful and debilitating this condition was. I was perplexed by the fact that I had previously encountered patients who were reported to have “crush fractures” on X-ray and yet they were entirely asymptomatic with no history of pain and dysfunction like that experienced by this elderly woman. I wondered at that time about the best way to manage her problem. My colleagues advised me to institute a back extension strengthening programme with the aim of reducing the kyphotic* deformity which had contributed to the problem. Of course, pain relief was the principal initial treatment but when the pain had settled I instituted a gentle strengthening programme. Because I was unable to follow her up, however, I was unsure of how effective the programme had been.

Some time later I was doing my own strengthening programme in the gym and noticed a number of older people doing back extension exercises in prone lying. I presumed that these had been prescribed to improve strength and thoracic spine posture. As I watched these people, however, I noticed that they didn’t seem to be extending their thoracic spines. Rather, they seemed to be hinging at their lumbar spines in order to achieve the lift required to raise their trunk from the floor or bench. They appeared not to be extending their thoracic spines at all. These observations were the origins of the work that comprises this thesis.

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* Hyperkyphosis is a term used to describe excessive kyphosis. The thoracic spine is curved so that it is concave anteriorly. This is called a kyphosis.

There is a tendency for the thoracic spine to become more hyperkyphotic over time [1] and the purported effect of this change in shape on the spine and periphery is a cornerstone of spino-musculoskeletal examination [2]. Nevertheless, the thoracic spine is largely under-investigated when compared to other areas of the spine [3, 4].

Physiotherapists use a number of techniques to treat thoracic hyperkyphosis but the actual evidence relating to the effective treatment of kyphotic posture is limited. The techniques used are based on sound principles such as stretching and strengthening, but the fact that they are so numerous is a testament to the lack of evidence in the field. Physiotherapists, of course, are not the only practitioners who view postural abnormality as a primary cause of musculoskeletal pain and dysfunction. Nor are they alone in believing that postural correction is an essential component of effective rehabilitation. Osteopaths and Chiropractors have very similar belief systems with respect to the effect and amelioration of kyphotic deformity in the thoracic spine [5].

The efficacy of the many interventions used to improve posture by reducing the thoracic curve is unknown. Indeed one group has suggested that the thoracic spine is essentially immobile and that any spinal movement that occurs actually takes place at the lumbar spine while giving the appearance of thoracic spine extension [6]. However, two studies have reported significant active range of movement *in-vivo* [3, 7] though the range decreased with increasing age. Similarly, some studies have reported reductions in kyphosis after a programme of therapeutic exercise [8, 9], however one of the studies was neither randomised nor controlled [8] and the other reported statistically significant improvement using one measure but not another [9]. These studies do, however, suggest that it is possible to reduce the kyphotic curve but they do not clarify which strategies are the most effective.

Strengthening of the muscles which extend (straighten) the thorax has been reported to reduce the kyphosis in post-menopausal women with significant kyphosis [10-12]. The evidence is, however, weak. The one randomised controlled trial which evaluated the effect of prone extension exercises on kyphotic angle did not find a significant difference between the control and the experimental group

[10]. It is therefore tempting to conclude that back extensor strengthening is not really relevant. However, it occurs to me that rather than conclude that extensor strengthening is not relevant; the problem here may have been the type of exercise used. It may be that extension from prone was not effective because it primarily targeted the lumbar spine extensors. Extension from a seated position might have been more effective. If so, this position would also be more accessible to the older person.

It has been suggested that pre-existing age-related hyperkyphosis itself may be the cause of vertebral fracture in the presence, or even absence, of primary osteoporosis [13]. The challenge, therefore, is not just to treat osteoporosis but to understand which are the most potent strategies for avoiding hyperkyphosis in the adult rather than how to reduce it once the deformity exists, as in the case of the elderly woman that I described. This requires a thorough understanding of the anatomy and mechanics of the thoracic spine, as well as a better understanding of what we are doing now and how effective our strategies are. In this way the acutely distressing and debilitating phenomenon of acute compression fracture in the vulnerable elderly may be avoided.

The aim of this thesis is to examine the efficacy of some of the interventions used by physiotherapists and other practitioners to reduce thoracic kyphosis in a range of people who do not have osteoporosis. Included in this cohort will be people with stroke. There are two reasons for their inclusion. First, a flexed posture is characteristic of people following stroke since their trunk extensors are weak [14, 15]. Since an upright posture is required for efficient mobility, reducing thoracic kyphosis might be an effective way of improving function. Second, there is controversy concerning whether resisted strengthening exercise is effective for people with stroke in view of the possibility of increasing spasticity and thereby reducing movement efficiency. There have been no studies which have evaluated the effect of back extension strengthening in people with stroke.

This thesis will include a comprehensive literature review. It is intended to set the scene and provide a thorough understanding of the clinical significance of hyperkyphosis, the anatomical knowledge (and lack thereof) of the thoracic spine, a review of the biomechanics, and what is known about the aetiology of hyperkyphosis. The many measurement devices are discussed in some detail because the device used in this set of experiments is novel. The literature pertaining to treatment options is discussed as well as a short overview on stroke. After the review, the chapters each describe separate studies which were designed and executed with the aim of informing the randomised controlled trial which forms the culmination of the thesis.

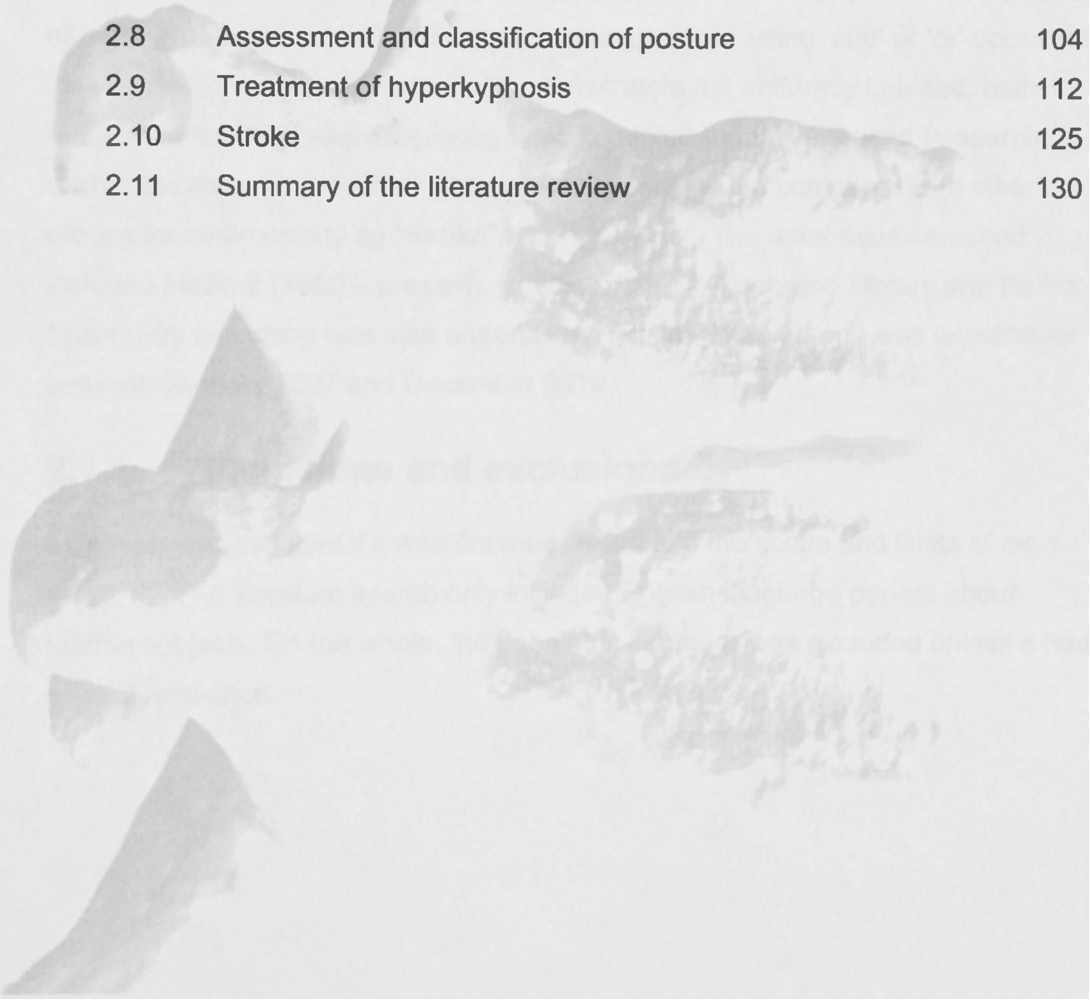
1.2. Thesis hypotheses

The main hypotheses being addressed in this work are:-

1. The flexible electrogoniometer is a valid and reliable device for the measurement the thoracic spine in the sagittal plane.
2. Physiotherapists in Australia use numerous strategies to treat hyperkyphosis and improve posture but strengthening, stretching and postural re-education are the main interventions.
3. The thoracic spine extends more in sitting than in prone lying.
4. The thoracic extensors are more active in sitting than they are in prone lying.
5. Muscle strength testing (myometry) of the back extensors in sitting is valid and reliable.
6. Progressive resisted strengthening of the back extensors in sitting is more effective than postural re-education for reducing thoracic curvature (kyphosis) and increasing physical function in people with and without stroke.

Chapter 2.

Literature review



2.1. Literature review methodology

The background information underpinning this thesis was found in the literature pertaining to kyphosis and, to a lesser extent, stroke. The literature review methodology and pertinent material are presented below.

The scope of this literature review and the search terms used are set out in the literature review search strategy outlined in Figure 2.1. The primary search term used was ‘kyphosis’ and the secondary term was ‘stroke’. These terms were combined with each other and the peripheral terms ‘thorax’, ‘physiotherapy’, ‘trunk muscles’, ‘posture’, ‘biomechanics’ and ‘measurement’ using ‘and’ or ‘or’ operaters. (see Figure 2.1). Because some of the terms were not uniformly indexed, both MeSH and keyword searches using various related terms were used to search each topic area. The resultant groups of terms were then compared with other groups for commonality eg “Stroke” and “Kyphosis”. The databases searched included Medline (1950 – present), Embase, Cinhal, Cochrane Library and Pedro. Secondary searching was also undertaken. The literature search was undertaken between January 2007 and December 2010.

2.1.1. Inclusions and exclusions

Literature was included if it was deemed relevant to the scope and limits of the research. The literature search only included English language papers about human subjects. On the whole, the paediatric literature was excluded unless it had special relevance.

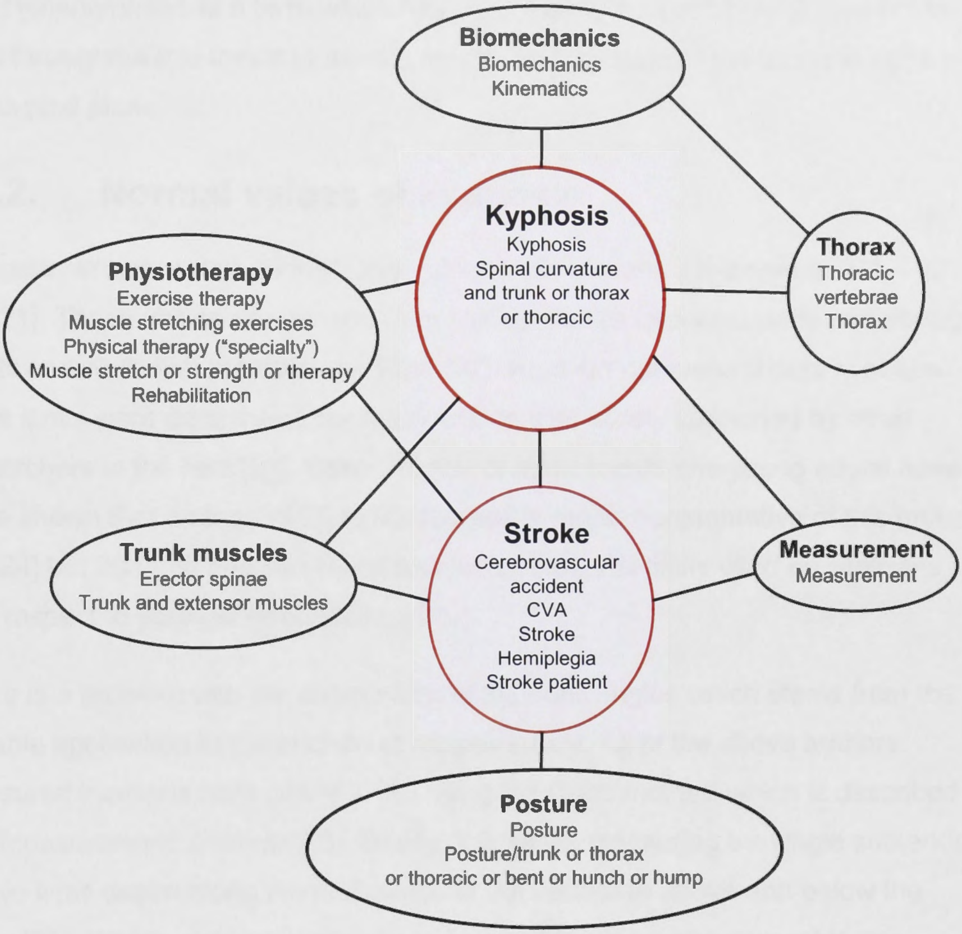


Figure 2.1 The literature review search strategy

Note: Terms inside the ovals were combined with the 'or' operator for more comprehensive capture Connecting lines indicate where the combined search terms were combined with the 'and' operator.

2.2. Kyphosis

2.2.1. Definition

Kyphosis is the word used to describe posterior convexity of the spine. It is derived from the Greek word *kūpho*, meaning bent. Strictly speaking 'kyphosis' implies an abnormally bent posture or 'humpback' but in common medical usage the term merely describes the direction of the thoracic curve with the prefixes *hyper-* or *hypo-* used when the curve is abnormally increased or decreased, respectively

[16]. Hyperkyphosis is a term which has been widely adopted [17-19] and will be used throughout this thesis to denote excessive curvature of the thoracic spine in the sagittal plane.

2.2.2. Normal values of kyphosis

The generally accepted normal range of kyphotic curvature is between 20° – 40° [20, 21]. These values are derived from limited studies of adolescents and young adults and were first published by Roaf [22]. Roaf did not present details of how these limits were determined but his definition was widely supported by other researchers in the field [23]. Other studies of adolescents and young adults have since shown that a range of 20 to 50 degrees is more representative of this group [20, 24] but 20 to 40 degrees remain as the operational limits used by clinicians with respect to younger populations [19].

There is a problem with the comparison of kyphotic angles which stems from the variable application of the method of measurement. All of the above authors measured kyphosis from lateral X-ray using the Cobb method which is described in the 'Measurement' section (2.6). Briefly, it involves measuring the angle subtended by two lines drawn along the end-plates of the vertebrae above and below the curve [25]. Which vertebra is chosen to be used for this measurement is an important consideration when comparing kyphotic angles because the angle increases or decreases depending on the number of vertebrae measured [26]. The most commonly cited 'end vertebrae' are T4 and T12 [19]. These do not necessarily represent the magnitude of the thoracic curve, but are commonly used because the vertebrae above T4 are difficult to visualize on standard lateral X-rays [27]. A summary of the various studies which have reported kyphotic angles for different age groups along with the measurement methods are shown in Table 2.1

The original studies of kyphosis were performed with a view to informing spinal surgeons for whom progressive kyphosis in adolescence was a significant problem [23] but the problem of kyphosis in the older population, particularly post-menopausal women, has also prompted studies of the older spine [1, 3, 7, 20, 21, 26, 28-39]. The results of these studies are shown in Table 2.1. Generally speaking these studies show that thoracic kyphosis increases with age [19] with the rate of increase being greater in females than males after they reach 40 years of age [20, 31]. This rate disparity decreases in the very elderly when kyphotic change is similar in men and women [28]. One longitudinal study of 100 Japanese elders (50-84) found that kyphosis (measured between T4 and T12) increased by a mean of 3 degrees over 10 years [38] but this increase is modest compared to other studies from the UK, Australia and the USA [3, 29, 30] which indicate that it can be more than double that figure after the 5th decade. In view of this natural increase in kyphosis with age some authors have suggested that the normal range more accurately lies between 20 and 45 or 50 degrees [40]. However, one study found that the distribution of kyphosis in the over 65 year age group was bimodal with a mean kyphotic angle of 41.9 degrees in the hyperkyphotic group and 28.3 degrees in the 'normal' group [30]. Thus there appears to be a discrete group for whom increasing age results in hyperkyphosis and others for whom it does not.

2.2.3. Normal dynamic range of movement

The study of the normal dynamic range of movement (ROM) in the thoracic spine is relatively unexplored. Early anatomic [41] and X-ray [42] studies concluded that thoracic spine flexion and extension was virtually non-existent. However, this has proved to be untrue. A number of studies have reported the ROM between erect and relaxed standing in different age populations [3, 7, 43-46] and values for segmental ROM from in vitro studies have been also been reported [47]. These are summarized in Table 2.2. However, the utilization of differing methodologies makes these studies difficult to compare. *In vitro* measurements of segmental sagittal rotation in the thoracic spine indicate that the amount of flexion and extension at each motion segment* increases in a cephalocaudad direction with the range in the

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* Motion segment.' Two adjacent vertebrae and the connecting soft tissues constitute a motion segment. In the thoracic region such a motion segment also includes the associated articulations of the ribs (48.Panjabi, M.M., Brand, R.A., Jr., and White, A.A., 3rd, *Mechanical properties of the human thoracic spine as shown by three-dimensional load-displacement curves.* J Bone Joint Surg Am, 1976. **58**(5): p. 642-52.)

upper segments being approximately 4 degrees, the mid segments being 5-6 degrees and the lower segments 9-12 degrees [47]. In a more recent *in vivo* study the mean ranges of inter-segmental motion were found to be similar except in the lower thoracic spine in which the mean total range between T9 and T12 was approximately 23 degrees which is less than 6 degrees per segment [49]. The subjects for these measurements were young adults between 18 and 24 years.

In studies which have examined the effect of age on range of sagittal movement a reduction of between 39% [7] and 60% [3] has been reported between the ages of 20 and 70 years (Table 2.2). There have been no studies which have documented the specific effect of aging on segmental levels nor have there been any studies about changes in range of kyphosis during activities of daily living.

Thus, although the thoracic inter-segmental movement in the sagittal plane is relatively modest compared to the cervical and lumbar segments (estimated at 8-20 degrees), the total capacity for movement is formidable [47] contributing up to 25% of the total spinal range [7]. This segmental movement however, is gradually reduced with increased age [3, 7] with increased stiffness being a hallmark of the aged spine [44].

Table 2.1

Papers reporting normal values of kyphosis (Cobb angle) with the vertebral levels from which the measurements were made.

Study	Subject N & demographics	Levels Measured	Angles reported
Goh et al. 2000 [50]	93 15 – 95 years	T4-T9	Approx 4° – 64° (actual data not reported
Singer et al 1990 [35]	145 males 141 females 15 – 93 years	T3-T11	M = 29.1° ± 10.7° to 47.5° ± 16.6° F = 27.8° ± 9.9° to 57.5°
Rajnics et al. 2001[51]	30 30-39 years	T4-T12	39.4° ± 10°
Schneider et al. 2004 [21]	854 females 553 males 50-96 years	T3-T12	F = 49° ± 16° M = 44° ± 13°
Bernhart & Bridwell 1989 [40]	102 5-29 years	T3-T12	36° ± 10°
Vedantam et al. 1998 [52]	88 10-18 years	T3-T12	38° ± 10°
Voutsinas & MacEwen 1986 [33]	251 males 419 females 5-20 years	T2-T12	37.6° ± 6.9°
Cowan 1965 [29]	139M (60-69) 167F(60-69) 163M(70-79) 133F(70-79)	T3-T11	42.6° ± 1.1° 50.0° ± 1.0° 49.3° ± 1.2° 55.8° ± 1.2°
Jackson et al. 1998 [53]	50 20-65 years	T1-T12	47° ± 9.7°
Jackson et al. 2000 [54]	20 26-75 years	T1-T12	44° ± 9.4°
Harrison et al. 2002 [55]	80 21-48 years	T1-T12	44.2° ± 12°
Itoi 1991[36]	100 osteoporotic females 48-89 years	T4 - inflexion (intermediate)	37.1° ± 3°
Stagnara et al. 1982 [32]	75 males 62 females 20-29 years	T4 - inflexion (intermediate)	37° (7°-37°)
Korrovesis et al. 2001 [37]	44 males 46 females Adolescents with round back deformity 10-20 years	T4 - inflexion (intermediate)	47.5° ± 3.53° (24° – 70°)
Fon et al (1980) [20]	316 2 – 77 years	Inflexion points	M = 20.88° ± 7°. F = 23.87°±6°
Thevnon et al. 1987 [34]	34 females (>60 years) 22 males (67.9±5.5)	Inflexion points	M = 39.2° ± 11° F = 43.5° ± 15.8°

Table 2.2

Dynamic range of movement measured in the thoracic spine

Paper	N	Age	Extent	Method	ROM (M ± F)	ROM (F only)
Melin and Poussa 1992 [43]	294 127 M 167 F	8-9	T1 – L1	Inclinometry	74.9° ± 12.8°	76.0° ± 11.1°
		10-11			77.8° ± 14.7°	80.7° ± 11.9°
		12-13			76.2° ± 13.8°	75.6° ± 12.6°
		13-14			66.9° ± 15.9°	62.8° ± 14.6°
		16-17			66.3° ± 14.6°	70.6° ± 10.0°
Miyakoshi et al. 2005 [45]	25	69.5 ()	T4 – L5	Lat X-ray	51.9° ± 14.9°	
Hinman 2004 [44]	20 F	29.2 (21-51)	T1 – T12	Flexicurve Range measured as % change in IK*		28.7 %± 13.3%
		72.3 (66-82)				9.6% ± 7. 9%
Mannion 2004 [46]	20 9 M 11F	45.4 ± 7.7	T1-2 to T11-12	Spinal Mouse	27.4° ± 13.3°	
O'Gorman & Jull 1987 [3]	120 F	22-29	T1 – T12	Inclinometers		70.4°
		30-39				53.3°
		40-49				43.6°
		50-59				33.9°
		60-69				25.7°
		70+				27.7°
Loebl 1967 [7]	176 84 M 92 F	15-20	T1-T12	Inclinometers	36°	33°
		21-30			32°	34°
		31-40			30°	28°
		41-50			26°	27°
		51-60			20°	23°
		61-70			25°	23°
		Over 70			19°	20°
White and Panjabi 1978 [47]			T1-T12	*In vitro*	64°	
Willems et al. 1996 [49]	30 M 30 F	18-24	T1-T12	Electromagnetic 3D analysis	58.5°	58.4°

Note. The measured values for thoracic range of movement differed depending on the measurement modality but the range is always seen to decrease with age.

ROM M ± F = range of movement where cohort was male or a combination of males and females.

ROM F only = range of movement where the cohort was female only.

The relative contribution of flexion and extension to the total range of movement is not clear. An early *in vivo* inclinometer study reported that the range of flexion and extension from the standing position were roughly equal [7]. A later *in vitro* [56] and a more recent *in vivo* study [49] however, showed that overall extension range is generally smaller than the flexion range. The *in vivo* study findings indicated that there was relatively more extension than flexion in the upper segments and less in the lower ones. Overall, however, the contribution of extension to the total range of sagittal movement was consistently less than flexion [49]. Investigations *in vitro* without the rib attachments showed that extension represented 30-42% of the total range of sagittal motion [56]. The effect of age on the differential loss of extension versus flexion range has not been specifically reported although there is a suggestion that extension range is possibly impeded by the apposition of the spinous processes which approximate each other more closely when the discs become narrowed due to degenerative changes [57].

In summary, although many studies have shown that mean angles for thoracic kyphosis increase with age, especially in women, this increase is not necessarily ‘normal’ since some older people do not become hyperkyphosed. It is also interesting that, in spite of research which would argue that 20 to 40 degrees is too narrow a band to classify as normal for an adult, this range is still commonly favoured by clinicians [58]. Range of thoracic spine movement, although reduced in the sagittal plane compared to the other spinal regions, is still responsible for up to 25% of the total spinal movement [7]. Finally, it is known that sagittal mobility in the thoracic spine decreases significantly with age, but information about the ROM during activities of daily living is, as yet, unreported.

2.2.4. Clinical significance

The prevalence of age-related hyperkyphosis is estimated to be between 20% and 40% of both men and women [59]. In women over 50 years the prevalence of vertebral deformity has been reported to be 25.3% [60] and over the age of 65 the prevalence of deformity has been reported as 50% in males and 65% in females [30].

As well as being cosmetically disfiguring, thoracic hyperkyphosis can cause pain and disability [61] as well as respiratory compromise [62]. An increase in kyphotic curve may also contribute to falls in the elderly [63] as well as increased rates of mortality [64]. Although increased kyphosis is a common feature of osteoporosis up to two thirds of people with age-related hyperkyphosis do not have decreased bone mineral density [21]. Further, there is some evidence to suggest that the incidence of osteoporotic fracture may be increased by pre-existing kyphotic deformity [13]. The effective measurement, treatment and prevention of thoracic hyperkyphosis is therefore an important healthcare challenge. In this section the literature relating to the mortality, morbidity and quality of life in people with hyperkyphosis will be presented.

2.2.5. Mortality

There is a consistent relationship between functional limitation and all causes of mortality [65]. Considering that older people with hyperkyphotic posture are more likely to have physical functional difficulties [61, 66], it is unsurprising that hyperkyphosis is related to increased incidence of mortality. This relationship was first noted over thirty years ago in a cohort of 239 men and 184 women between 70 and 89 [64]. The authors were surprised to find that amongst other factors such as blood pressure and grip strength, only age and degree of kyphosis were related to survival time. A later study found a relationship between degree of kyphosis and mortality in males only [28]. In order to clarify the effect of hyperkyphosis as distinct from osteoporosis on mortality Kado et al. (2009) examined 610 women aged between 67 and 93 years. They discovered that women with greater kyphosis were at increased risk of earlier death even after adjustment for age, osteoporosis and vertebral fracture [67]. Therefore, whether it is due to the decreased mobility secondary to hyperkyphosis, or because the effects of general degeneration are acutely reflected in the degree of kyphosis, there appears to be a significant relationship between mortality and degree of kyphosis

2.2.6. Morbidity

The loss of range of movement and increased stiffness that accompanies hyperkyphosis has been reported to be associated with decreased function [61, 66, 68-70], increased energy expenditure [70], pain and dysfunction of both spine [6] and shoulder [71], falls [63, 72-76], respiratory compromise [62, 77-79], increase in the risk of osteoporotic fracture [13], and depression [68]. The difficulty in interpreting these results lies in differentiating between the underlying osteoporosis which afflicts many of the participants in the studies of hyperkyphosis, and the postural deformity itself. In this section the literature pertaining to the relationship between the problems which are commonly cited as being associated with hyperkyphosis will be presented and, where possible, the effect of osteoporosis will be discussed.

2.2.6.1. Decreased function

There have been a number of studies which have sought to evaluate the effect of hyperkyphosis on physical function [61, 66, 68-70] but only one study controlled for osteoporosis [66]. Controlling for osteoporosis is important because it is independently associated with loss of strength which impacts upon function [80, 81]. In the studies which did not control for osteoporosis kyphosis was reported to be associated with significantly decreased walking and stair climbing speed [61] and reduced gait and balance scores [68]. In the one study where the statistical model was adjusted for age and bone mineral density, the functional measure of time taken to stand from a chair five times was still significantly greater in people with increased kyphosis [66].

2.2.6.2. Spinal pain

Interactions between thoracic spine posture and mobility are believed to play a role in the development of spinal pain syndromes [6]. However, the available evidence does not necessarily support this view [2]. Increased kyphosis is thought to result in compensatory hyperlordosis and low back pain [68] but whereas age has been demonstrated to be related to thoracic curvature, lumbar lordosis has not [82]. In contrast with clinical beliefs a study of neck/shoulder pain in adolescents found no association between cervicothoracic postures and pain [83].

A large study of 610 women aged between 65 and 91 years revealed that women with hyperkyphosis did not have more back pain or back problems compared to those with normal kyphosis [84]. However, in a study of 6439 osteoporotic women of a similar age, hyperkyphosis was related to significantly greater self reported middle and upper back pain [85]. However, it is possible that in this cohort with osteoporosis the participants had pain secondary to vertebral fracture rather than pain due to the kyphotic posture itself.

Therefore, in spite of clinical beliefs that increased kyphosis increases spinal pain [6], to date there is no convincing evidence in support of this position unless associated with fractures or degenerative disease.

2.2.6.3. Shoulder pain and dysfunction

Mobility of the thoracic spine is essential for normal shoulder kinematics. Shoulder elevation is coupled with upper thoracic rotation and extension of the thoracic spine (lower more than upper) [86]. A study which compared older and younger women found that in older women a large kyphosis was related to reduced arm elevation and in younger women the range of elevation was strongly associated with the range of thoracic extension they used [87]. Scapular dynamics have been reported to be influenced by increased thoracic kyphosis with kyphosis being associated with increased scapular protraction and reduced pectoralis minor length [71]. which impedes shoulder rotation during flexion and increases the likelihood of subacromial impingement syndrome [88]. Thus the relationship between the loss of thoracic extension and shoulder dysfunction has been well established. However, the prevalence of shoulder pain in conjunction with thoracic hyperkyphosis is not clear.

2.2.6.4. Falls

A number of studies have reported an increased incidence of falls, or risk of falls, in people with hyperkyphosis [63, 72-76]. However the findings of two other studies did not support this view [89, 90]. In a study which compared osteoporotic women with low and high levels of kyphosis as well as the presence of vertebral fractures, it was the presence of a fracture and not the degree of kyphosis which was found to result in significant balance impairment [89]. In another study, older women with hyperkyphosis and decreased lumbar lordosis were more likely to have fallen in the year preceding the study [76]. This was supported by a study which measured the contribution of a loss of lumbar lordosis to falls risk and found that it better predicted an increased incidence of falls than the degree of thoracic kyphosis [90]. Another study found that both the loss of lumbar lordosis and an increase in kyphosis were associated with increased falls risk [76]. On balance therefore, although there is a strong suggestion that increased kyphosis may not be an independent predictor of falls risk, it would still seem to be a significant contributor to the balance impairments which predispose the elderly to falls.

2.2.6.5. Respiratory compromise

There is considerable evidence of reduced respiratory function as a result of age-related hyperkyphosis [62, 77-79]. A study which aimed to differentiate between the postural deformity and the effect of underlying osteoporosis found that osteoporotic women without fracture or kyphosis did not display the deficits on pulmonary function testing seen in kyphotic osteoporotic women however they did demonstrate greater fatigue of the respiratory muscles compared to controls [91]. Hyperkyphosis, therefore, seems to be related to reduced respiratory function.

2.2.6.6. Increased risk of osteoporotic fracture

The presence of a pre-existing kyphotic deformity has been shown to result in a 1.7-fold increased risk of having a future fracture independent of age, prior fracture, and spine or hip bone mineral density (BMD) [13]. The forces borne by the anterior elements of the vertebrae per unit of load increase with increasing thoracic curvature [92]. After the age of 50 years the vertebral bone begins to weaken thereby making it more vulnerable to failure under load [93]. The significant role of hyperkyphosis in the osteoporotic fracture cascade has been the rationale for a number of intervention studies which have aimed to reduce the extent of kyphotic posture in elderly women in particular [8, 10, 94-100].

2.2.6.7. Emotional and Psychological problems

Hyperkyphosis has been reported to lead to a distorted body image and poor health perception [101]. It is, as has been the case in the preceding sections, difficult to tease out the effects of osteoporosis from the posture itself. Osteoporotic women with vertebral fractures have been shown to demonstrate increased psychiatric symptoms, psychosocial problems and poor health perception when compared to age matched controls [102]. These changes may not however apply only to hyperkyphosis. A Japanese study found that elderly people with a variety of trunk deformities including thoracic kyphosis, flat back and increased lumbar lordosis tended to score lower than the normal group with regard to subjective healthiness and life satisfaction measures [103]. In a study of elderly women with flexed posture those with severe flexed posture demonstrated greater depression and reduced motivation when compared to those with mild flexed posture [68]. Of interest is that osteoporosis was not significantly related to flexed posture in this group which indicates that it was the posture itself that resulted in the psychological differences.

2.2.6.8. Quality of life

The diagnosis of osteoporosis itself can have deleterious psychological effects [104]. So, although there are a number of studies which have measured the effect of kyphosis on quality of life in women with osteoporosis [45, 70, 73, 105] there are few which can be used to assess the effect of hyperkyphosis alone. A Japanese study of post-menopausal women which assessed the quality of life according to posture type found that, compared to those with normal posture, all groups had a decreased quality of life but those with ‘whole spine kyphosis’ i.e. lumbar and thoracic, had the lowest scores [45]. A large French study of women aged 36-92 years found that hyperkyphotic women reported significantly more difficulty with physical tasks and the need to make more adaptations to their daily lives whether or not they had osteoporotic fractures [105]. Therefore, on current evidence it would seem that hyperkyphosis, with or without osteoporosis, impacts significantly on quality of life. Data for the effect on men has not been published.

2.2.6.9. Summary

Thoracic hyperkyphosis is detrimental to normal physical function as well as emotional and psychological wellbeing. It is also related to increased mortality in the elderly. Although hyperkyphosis can be the result of osteoporotic fracture, it is an independent risk factor for falls.The evidence for a relationship between hyperkyphosis and spinal pain is not conclusive but hyperkyphosis has been shown to result in shoulder dysfunction. For all of these reasons prevention of excessive age-related kyphosis is an important healthcare challenge for an aging population.

2.3. Anatomy of the thoracic spine

In designing an RCT of interventions for hyperkyphosis an understanding of the anatomy is essential. This summary of the anatomy is pertinent to the various studies described in the following chapters as well as the other sections of the literature review. The anatomy of the thorax and thoracic spine is reasonably well described in the anatomy textbooks. For this reason much of the information presented in this review of the anatomy is derived from three sections of the 40th Edition of Gray's Anatomy, section 5 [106], section 6 [107] and section 7 [108]. In order to make this section less cumbersome, the reader should assume that these are the sources unless otherwise indicated.

The thoracic spine lies between the seven cervical vertebrae above and the five lumbar vertebrae below. There are usually 12 thoracic vertebrae but occasionally there are 13 and one case of 15 has been reported [4]. Between each pair of vertebrae there is an intervertebral disc. One cannot consider the thoracic spine in isolation since it is part of a larger functional unit called the thorax (Figure 2.2). The skeletal thorax consists of the vertebrae posteriorly, the manubrium and sternum anteriorly, and the adjoining ribs. The anatomy of the bony elements, the joints, some of the ligaments, the muscle groups which influence the thoracic spine, and the thoraco-lumbar fascia will be described in this section.

2.3.1. The vertebral bodies

In the thoracic spine, the vertebral body is heart-shaped or triangular in transverse section with its apex pointing ventrally. Thus the cross sectional area is reduced anteriorly [18] (Figure 2.3). The height and width of the vertebrae decreases from T1 to T4 and then increases again from T5 to T12 and further again to L5. Thus, rather than being a continuous pyramidal shape with its base at L5, the shape of the spine appears as two opposing pyramids communicating at T4 [109]. The increase in vertebral body size from the T4 down is in keeping with increasing load-bearing requirements [4]. Behind the vertebral body is the vertebral foramen, a roughly circular hole through which the spinal cord runs. This hole is normally smaller in the thoracic spine than it is in either the lumbar or cervical regions [110] (Figure 2.3). The vertebral foramen is surrounded posteriorly by the 'neural arch' which consists of the pedicles and the laminae (Figure 2.3).

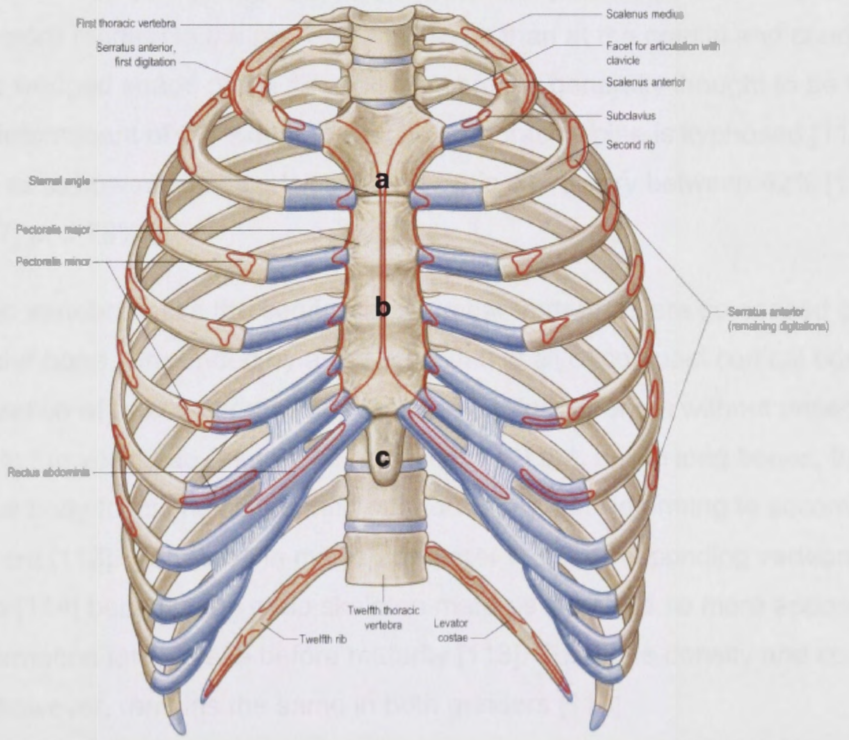

Figure 2.2 The thorax

From *Gray's Anatomy*. 40 ed. 2008, New York: Churchill Livingstone with permission.

Note. Parts of the sternum **a**. manubrium **b**. body **c**. xiphoid process

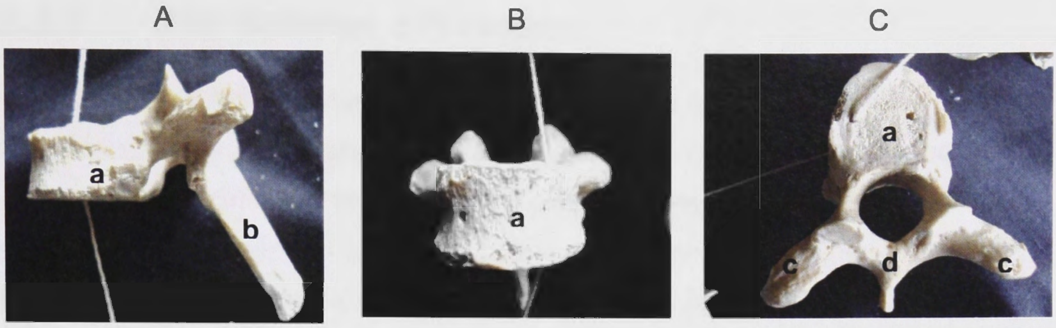

Figure 2.3 The 7th thoracic vertebrae (T7). A. sagittal view; B. frontal view; C. axial view. a. vertebral body; b. spinous process; c. transverse process; d. neural arch

As stated above, when viewed in sagittal section, the thoracic vertebral bodies in adults are thicker posteriorly than they are anteriorly making them wedge-shaped. This is more marked in the mid-thoracic region than at the cranial and caudal ends [4]. The wedged shape of the thoracic vertebrae is generally thought to be the major determinant of the extent to which the thoracic spine is kyphosed [111] but reports as to how much it explains the kyphotic curve vary between 42% [112], 55% [17] and 78% [1].

Thoracic vertebrae, like the cervical and lumbar vertebrae, are composed of trabecular bone surrounded by a relatively thin shell of compact cortical bone. This configuration of trabecular and cortical bone confers strength without unnecessary weight to the vertebrae (as with all bone material) but, unlike long bones, the vertebral body functions as a spring or shock absorber deforming to accommodate movement [113]. Vertebrae in males are larger than corresponding vertebrae in females [114] because the male skeleton matures later and so more appositional bone formation takes place before maturity [113]. The bone density and cortical depth, however, remains the same in both genders [113].

2.3.2. The spinous processes

Behind the vertebral foramen, and most posteriorly, is the spinous process (Figure 2.3). The spinous processes in the thoracic spine are long and angled caudally. The spinous processes from the T5 to T8 overlap posteriorly with T8 being the most oblique. The spinous processes below are less obliquely angled and shorter, and by T11 and T12 the processes are triangular with blunt apices resembling those of the lumbar vertebrae. The spinous processes are used clinically to determine vertebral levels but, because their angulations vary, their position with respect to the vertebral body is not consistent (Table 2.3).

The thoracic spinous processes, as in the other parts of the spine, provide protection for the spinal cord and nerve roots, as well as providing attachment and acting as levers for the muscles of the trunk [110].

Table 2.3

Position of the tips of the thoracic spinous processes with respect to the underlying vertebrae.

Spinous Process	Position of the tip of the spinous process with respect to the vertebral body.
T1,2 and 3	In line with their own transverse processes.
T4, 5 and 6	Angled slightly caudally so that their tips are about mid-way between their own transverse processes and those of the vertebra below.
T7, 8 and 9	Level with the transverse process of the vertebra below.
T10	Level with the transverse process of T11
T11	Midway between T11 and 12
T12	At the same level as T12 vertebra.

Note. Based on information in Grieve, G., *Common Vertebral Problems*. 2nd ed. 1988, Edinburgh: Churchill Livingstone.

2.3.3. The transverse processes

The transverse processes project laterally, backwards and slightly upwards behind the relatively short pedicles (the name given to the bone which forms the side of the vertebral foramen). The transverse processes from T1 to T12 shorten progressively in a caudal direction. From T1 to T10 the transverse processes have an ovoid facet on the anterolateral surface near its tip (Figure 2.4 c). This facet articulates with the tubercle of the corresponding rib via a synovial joint. The first five or six facets are concave and face antero-laterally. Thereafter the facets become flatter and face superolaterally thus accommodating the greater loading demands from the upper limb and thorax [4]. The rib is strongly attached to the transverse process by the costotransverse and lateral costotransverse ligaments.

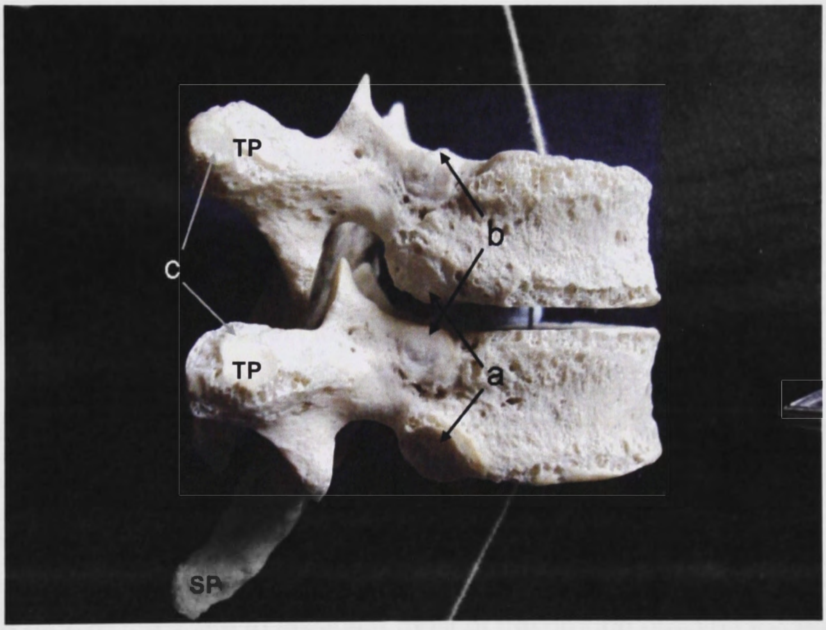

Figure 2.4 The costovertebral facet joints

Sagittal view. **a**. inferior facets for costovertebral joint; **b**. superior facets for the costovertebral joint; **c**. facets for costotransverse joints,

TP = transverse process, **SP** = spinous process

2.3.4. The sternum and ribs

The sternum consists of three parts: the manubrium cranially, the xiphoid process caudally, and the body in between (Figure 2.1). It slopes inferiorly and anteriorly and is convex in front and concave behind. The ribs attach to the sternum via the costal cartilages and the sternochondral joints. The first sternochondral joint is fibrous, conferring considerable stability to this level. Below this, the joints are synovial. The 8th, 9th and 10th ribs articulate with the sternum indirectly via cartilaginous bars which coalesce with the seventh costal cartilage rendering these ribs more flexible [115]. The sternum provides anterior joint attachments for the ribs thereby completing the 'cage' with a structure that is stable but mobile.

2.3.5. The intervertebral joint

Between each of the vertebral bodies of the spine are fibrocartilaginous discs which, together with the cartilaginous vertebral end-plates, form the intervertebral joint which is classified as a symphysis (Figure 2.5) [116].

2.3.6. The intervertebral discs

The human intervertebral disc has been studied extensively and yet it remains a structure of tremendous interest to researchers because the preservation of healthy discs is believed to be the key to a healthy spine [117]. The primary role of the intervertebral disc is to bind the vertebrae together while permitting the combined vertebrae and discs to function as a column which is flexible but capable of supporting the body [118]. The discs also have a shock-absorbing role, especially in humans who are bipedal but who walk with extended knees and who therefore require the spine to dissipate most of the ground reaction forces [116]. Of all the intervertebral discs, only the thoracic ones have any assistance in this role in the form of shared weight bearing via the ribs and the costovertebral joints. This may partly explain the lower comparative incidence of disc disease in the thoracic spine [116].

All of the intervertebral discs comprise three histologically distinct layers: a layered annulus (annulus fibrosus), a gelatinous nucleus (nucleus pulposus), and a vertebral end-plate above and below [119]. Each component has distinct properties. The nucleus pulposus is rich in proteoglycans and acts as an internal semi-fluid mass while the annulus fibrosus, which is rich in collagen, acts as a laminated fibrous container [120].

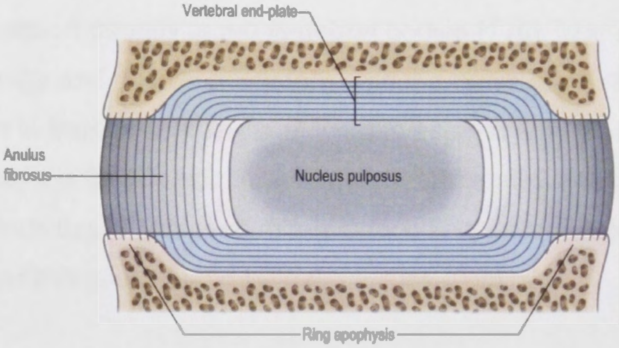

Figure 2.5 The components of the intervertebral disc

From *Gray's Anatomy*. 40 ed. 2008, New York: Churchill Livingstone with permission.

The thoracic discs are rounder, less wedge-shaped and narrower than either the lumbar or the cervical discs with the minimum disc height being found at the T4-5 level [121]. The shape and dimensions of the thoracic discs probably reflect the relative immobility of the thoracic spine and the relative bias towards rotation [121]. The thoracic discs are attached to the rib heads via the intra-articular radiate ligaments [119].

Each of the main components of the intervertebral disc will be briefly described below.

2.3.6.1. The annulus fibrosus

The annulus fibrosus forms the outer boundary of the disc. It has a narrow outer collagenous zone and a wider inner fibrocollagenous zone. The annulus is comprised of concentric laminated bands in which collagen fibres are arranged obliquely at 69° to the axis of the spine, alternating in direction in each successive lamella [121]. The angulation of the annular fibres enables the disc to convert compressive stresses into tensile stress which is an important mechanism by which the disc transfers compressive loads from one vertebra to another [111]. The annulus surrounds the nucleus, connecting to the cartilaginous end-plates in all but the outermost layer. These outer fibres are known as Sharpey fibers or perforating fibers, and they attach directly to the vertebral bodies [116]. The annulus tends to be thicker anteriorly and thinner posteriorly with the nucleus situated slightly posteriorly, even in the thoracic spine which curves anteriorly [116]. The annulus dissipates load as it is transferred from one vertebral end-plate to the next [111]. The mode by which this is achieved differs depending on the water content of the nucleus [111] and this is explained below.

2.3.6.2. The nucleus pulposus

At birth the nucleus is relatively large and soft, containing mucoid material and notochordal cells as well as some collagen fibres from the surrounding annulus [122]. The nutritionally demanding notochordal cells disappear in the first decade and are replaced by chondrocyte-like cells [123, 124]. As the disc ages the fibril diameter of the type I collagen in the nucleus begins to resemble the type II collagen found in the annulus [116]. In addition, the aggregated proteoglycans which maintain the water content within the nucleus, begin to decrease while the keratin chondroitin-sulphate ratio increases [116, 120, 125]. Increased cross-linking between the proteoglycans and the collagen within the nucleus results in reduced water-binding capacity and increased stiffness [117]. In the early years of life the nucleus has enough water content to act as a fluid so that when vertical load is applied to it the pressure in the nucleus increases and the load is spread in all directions i.e. to the annulus as well as to the end-plates [111]. In this way the nucleus is able to share the load over the whole disc converting compressive stress to tensile stress borne by the annular fibres [111]. As the nucleus dries out, more of the load is compressive and is transferred directly from end-plate to end-plate via the annulus [111]. Interestingly, there is a possible advantage to disc degeneration. It has been suggested that the degenerated disc is less likely to cause deformation of the vertebra above it, possibly because of the decreased concentration of load being transferred to the vertebral end-plate from a well-hydrated nucleus [126].

2.3.6.3. The vertebral end-plates

Above and below each disc are the vertebral end-plates (Figure 2.5 and Figure 2.6). The end-plates separate the vertebral body from the discs. They are comprised of a thin layer of hyaline cartilage and a perforated plate of bone [127]. The epiphyseal growth plate is situated beneath the end-plate in the young [127]. The perforations in the bony element of the end-plate allow capillary buds to provide nutrition to the discs via small solute diffusion as well as larger solute mass fluid transfer in response to diurnal fluid flow [128]. The cartilaginous layer, which persists into maturity, merges with each disc via the lamellae of the inner annulus [129]. The end-plate is usually less than 1 mm thick and is thinner at its centre, above and below the nucleus pulposus [129]. The end-plate is held in place by Sharpey fibres which surround it [116]. The end-plate absorbs considerable mechanical pressure because it is deformable, allowing some of the force exerted by the nucleus during compression to be ‘accepted’ without damage to the vertebral body [130] . However, excessive compression forces can lead to crushing of the underlying trabecular bone and cracking of the overlying end-plate [118].

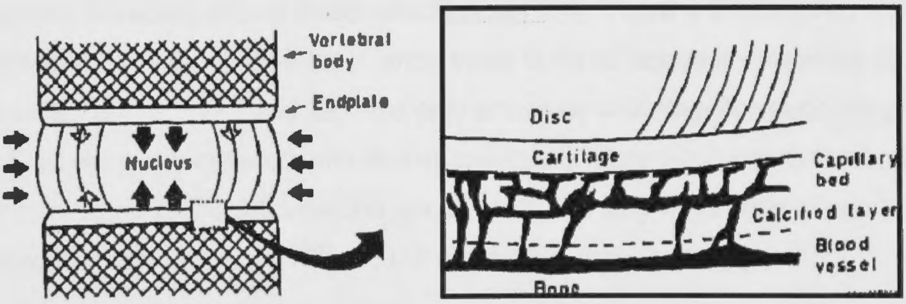

Figure 2.6 The vertebral end-plates

From Holm, S., et al., *Nutrition of the intervertebral disc: solute transport and metabolism.* Connect Tissue Res, 1981. 8(2): p. 101-19 with permission

2.3.7. The costovertebral joints

The rib articulations, which are a unique feature of the thoracic spine, occur on both the body as well as on the transverse processes of the thoracic vertebrae (Figure 2.4). At the posterior end of each rib, the head articulates via a synovial joint with the vertebral body. As it curves back, a separate synovial articulation occurs between the rib tubercle and the vertebral transverse process. These joints are collectively called the costovertebral joints [110] and specifically they are the costocorporeal and costotransverse joints [108]. However, the costocorporeal joint is commonly referred to as the costovertebral joint in the literature [119, 131, 132] and this convention is adopted here to avoid confusion.

In general, each vertebral body has two facets on each postero-lateral aspect [133] (Figure 2.4). The larger facet is situated at the inferior margin of the vertebral body, at the junction with the pedicle. The smaller 'demifacet' is positioned correspondingly at the superior margin. The head of each rib articulates primarily with its corresponding vertebra via the larger inferiorly located facet, but also with the superior demifacet of the vertebra below and the intervening intervertebral disc. The joint is therefore made up of the rib head, the two adjacent vertebrae and the intervening disc. At the disc, the joint is divided by an intra-articular ligament which is attached to the lateral aspect of the disc thereby dividing the superior and inferior facets and providing strong discal attachment [134]. There are, however, exceptions. T1 has only one facet since there is no rib above it with which to articulate. The 10th, 11th and 12th ribs only articulate with their corresponding vertebrae via superior facets situated successively more inferiorly on the body when compared to the articulations above [119]. T9 may have a demifacet with which to articulate with the 10th rib, but most often it does not [4].

The development of the superior demifacet is delayed until early adolescence with the completion of secondary ossification in the rib head [135]. This is probably one factor which contributes to the flexibility of the young thorax [115]. The ligamentous support for these joints includes strong capsular ligaments (including the intra-articular ligaments mentioned above) as well as the radiate ligaments which hold the head of the rib firmly against the facet joints by fanning superiorly, anteriorly and inferiorly [136].

The anterior capsule of the costovertebral joints is innervated by a plexus of small nerves which arise from the sympathetic trunk [137, 138]. Some of the fibres from this plexus proceed to the disc and other ligamentous structures [137]. This rich and complex innervation suggests a somatosensory role [138]. Mechanoreceptors in the costovertebral joints may contribute to reflex respiratory and postural regulation [139, 140].

2.3.8. The sternocostal joints

The ribs attach to the sternum via the costal cartilage and the sternochondral joints. The sternal facets of this joint are concave. The first sternochondral joint is fibrous conferring considerable stability to this level. Below this the joints are synovial. The seventh rib articulates with both the xiphoid and the sternum. The 8th, 9th and 10th ribs articulate with the sternum indirectly via cartilaginous bars which coalesce with the seventh costal cartilage. This indirect attachment makes these ribs more flexible than those above [115].

2.3.9. The zygapophyseal joints

Each vertebra has both superior and inferior articular processes which make up the zygapophyseal joint surfaces. In the thoracic spine these are just medial to the base of the transverse processes. Clinically, these joints are often called the 'facet joints' but it is less ambiguous to call them the zygapophyseal joints since there are other facet joints associated with the rib articulations (i.e. costovertebral and costotransverse joints) [141]. From T1 to T11 the superior zygapophyseal joint surfaces are thin and almost flat presenting a gentle curve in both the sagittal and transverse planes [119] and permitting multidirectional movement [115]. They face posteriorly, a little laterally and upwards and articulate with the anterior-facing inferior facet of the vertebra above [56] (Figure 2.7). The surfaces of the inferior facets are correspondingly directed a little medially and downwards. The inferior facet of T11 and its corresponding surface on T12 differ in that they face mediolaterally as in the lumbar spine. This change in direction occasionally occurs one level higher or lower but, in any case, alters the spinal mechanics from a rotational to a non-rotational function more characteristic of the lumbar spine.

Asymmetry of the zygapophyseal joints has been found to be a normal occurrence in the thoracic spine with the right side being slightly more angled in both the sagittal and transverse planes [142]. Of note is the fact that this asymmetry does not occur in the lumbar spine.

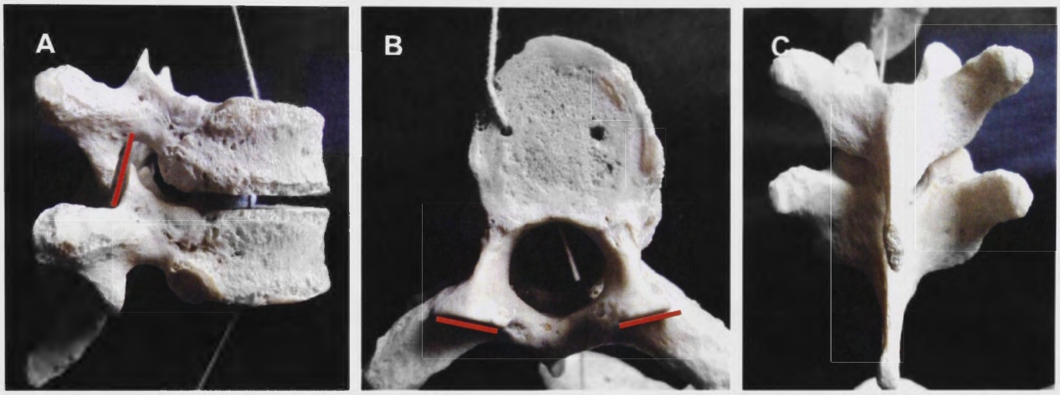

Figure 2.7 The zygapophyseal joints at T7/T8.

A. Sagittal; B. Axial; C. Posterior. Red lines show the angulation of the articular surfaces.

2.3.10. The ligaments

The ligaments of the spinal column have many different functions. Crucially, they protect the spinal cord by limiting movement within well-defined limits while also permitting adequate motion to allow normal movement. They are also able to resist sudden high loads which might injure the spinal cord. In the thoracic spine, the ligamentous system is principally designed to resist flexion and extension. Limitation of rotation and lateral flexion are performed by the costovertebral attachments [4]. There are many ligaments in the thoracic spine but only the larger ligaments will be presented here.

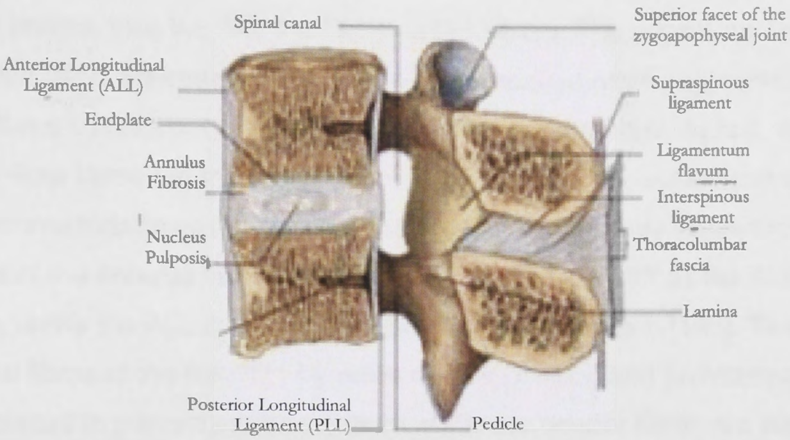

Figure 2.8 The ligaments of the spine

Based on a figure from *Gray's Anatomy*. 40 ed. 2008, New York: Churchill Livingstone with permission.

2.3.10.1. The anterior longitudinal ligament

The anterior longitudinal ligament (ALL), which attaches to the anterior vertebral bodies from the base of the skull to the sacrum (Figure 2.8), is narrower and thicker in the thoracic region [111]. It is attached firmly and widely to the vertebral bodies but its attachment to the annulus fibrosus is narrow. The ALL attaches directly into the cortical bone of the vertebral bodies and is intrinsically woven into the annular fibres of the disc [4]. It is primarily composed of type II collagen and is therefore essentially inextensible [143]. Its superficial fibres run parallel down the whole length of the spinal column while its deeper layers cross each other obliquely at about 80° and insert into the annulus. The ALL has the highest tensile strength of all the vertebral ligaments [143].

2.3.10.2. The posterior longitudinal ligament

The posterior longitudinal ligament (PLL) runs within the spinal canal over the length of the vertebral column passing over the posterior surfaces of the vertebral bodies (Figure 2.8). In contrast to the ALL, the PLL is very firmly attached to the annulus via interwoven connections which are wider than their attachment to the vertebral bodies. Like the ALL the PLL has two layers. The superficial layer is a strong wide band whereas the deeper layer is arranged more segmentally, its oblique fibres fanning out to insert into each intervertebral disc. In fact, although the superficial fibres run the length of the spinal column, the superficial and deep fibres become indistinguishable adjacent to each disc, as they mesh together with the fibres of the annulus fibrosus [144]. The PLL is not as stiff as the ALL [143] because, unlike the ALL it contains elastin as well as collagen [145]. The superficial fibres of the the PLL, by virtue of their position and architecture seem to be well-placed to prevent extreme flexion, while the deeper fibres are well-placed to control the range of rotation and lateral flexion between each segment [144]. Ossification of the posterior longitudinal ligament is a condition which occurs primarily in Asian populations [146] but has been reported also in Caucasians [147].

2.3.10.3. Ligamentum flavum

The ligamentum flavum lies within the vertebral canal and connects the laminae of adjacent vertebrae (Figure 2.8). It attaches from the zygapophyseal joint capsules on each side, to the point where the laminae fuse to form the spinous process centrally. At this point the ligaments partially unite but allow the passage of venous plexuses. Their course takes them from the anterior aspect of the lamina above to the posterior aspect of the lamina below. The yellow colour of these ligaments is due to their high elastin content [148]. Their function is to control the separation of the laminae during spinal flexion as well as to potentially assist with the restoration of an erect posture, though this role is probably minimal [149]. The incidence of ossification of the ligamentum flavum is high in Asian countries like Japan and has been shown to have a higher incidence in people with hyperkyphosis [150]. Since ossification also occurs in the posterior longitudinal ligament, which also contains elastin, it is thought to result from localized mechanical stress on elastin fibres [150]

2.3.10.4. Interspinous ligaments

The interspinous ligaments, as their name implies, connect the spinous processes (Figure 2.8). They connect the inferior to the superior edges of consecutive spinous processes running obliquely inferiorly and ventrally. They are not present in the cervical spine and in the thoracic spine they are narrow and elongated. They are paired and better developed in the lumbar spine.

2.3.10.5. The supraspinous ligament

The supraspinous ligament connects the tips of the spinous processes posteriorly (Figure 2.8) running the length of the spine between C7 and L4 or 5. Though it is often deficient, when present it is a strong fibrous cord with fibres that span three or four levels superficially, decreasing to fewer at deeper levels. Most of the ligament is formed by the tendons (or aponeuroses) of muscles which insert into the midline such as trapezius, semispinalis, longissimus etc.

2.3.11. The muscles acting on the thoracic spine

There are many muscles which influence the thorax and it is outside the scope of this thesis to detail all of them. The reader is advised to consult an anatomy textbook for specific information about particular information such as muscle origins and insertions. This section is concerned with discussing how some muscles impact on the thoracic spine in order to prepare the reader for subsequent sections in this chapter, as well as later chapters.

2.3.11.1. Splenius capitis, splenius cervicis and semispinalis cervicis.

Even though the splenii are neck extensors and rotators, they insert into the upper thoracic spine beneath the rhomboids and trapezii and above the erector spinae. Their insertion coincides with the narrowest point in the thoracic spine at about T4 (2.3.1). It has been suggested that this configuration points to T4 being an important axis of rotation for lateral flexion (and possibly extension) of the neck on the thorax [109]. This theory is supported by an *in-vitro* study of spinal segmental mobility which found that the mobility of the segments from T1-T4 was greater than anywhere else in the thoracic spine [151].

2.3.11.2. The spinotransverse group

These deeply-situated muscles include the rotatores, multifidus and semispinales. As their names suggest, they all have fascicles which run between the spinous processes and the transverse processes. They vary in length, usually spanning between one and six segments. Rotatores are the deepest and shortest and semispinales are the longest and most lateral. By virtue of their position they are classified as spinal extensors though it has been postulated that they may primarily have a stabilising role [115] (2.3.11.11 below).

2.3.11.3. The interspinales and intertransversarii

In the thoracic region these muscles are poorly developed and occur only at the top and bottom of the thoracic spine. It has been suggested that their primary role may be proprioceptive.

2.3.11.4. The erector spinae

The erector spinae are a large musculotendinous mass which occupies an intermediate position between the deeper muscles described above and the superficial groups which will be described below (Figure 2.9). They are labelled according to the spinal region they primarily occupy and the spatial location of their attachments. Spinalis is the most medial, longissimus more lateral and iliocostalis the most lateral. Spinalis thoracis has long fascicles which connect the spinous processes of the upper thoracic vertebrae to the lowest thoracic and upper lumbar vertebrae merging with longissimus at its lateral margins. Spinalis is most developed in the thoracic spine. Longissimus thoracis is the largest component of the erector spinae. It consists of many small fascicles with long caudal tendons which aggregate to form a wide caudal aponeurosis. Both the thoracic and lumbar parts of iliocostalis exert an influence on the thoracic spine. The thoracic part connects the upper six ribs to the lower six at their rib angles. The lumbar part arises at the rib angles of the lower eight or nine ribs and combines with the longissimus thoracis tendons (described above) to form the erector spinae aponeurosis which together insert into the lumbar spinous processes, the sacrum and the ilium. A portion of the uppermost fibres of gluteus maximus arise from the erector spinae aponeurosis from which it has been proposed that they might exert an influence on the spine [152]. By virtue of the thoracic attachments described above it is reasonable to assume that the influence of the gluteals may extend to the thoracic spine. The erector spinae are powerful extensors of the thoracic spine and when they act unilaterally they also laterally flex the spine. Of interest are the results of an *in-vitro* study of the thoracic erector spinae muscles which showed that their sarcomere lengths indicate that they develop greater forces at body positions that elongate the muscles relative to the supine position [153]. In other words their form favours kyphosis.

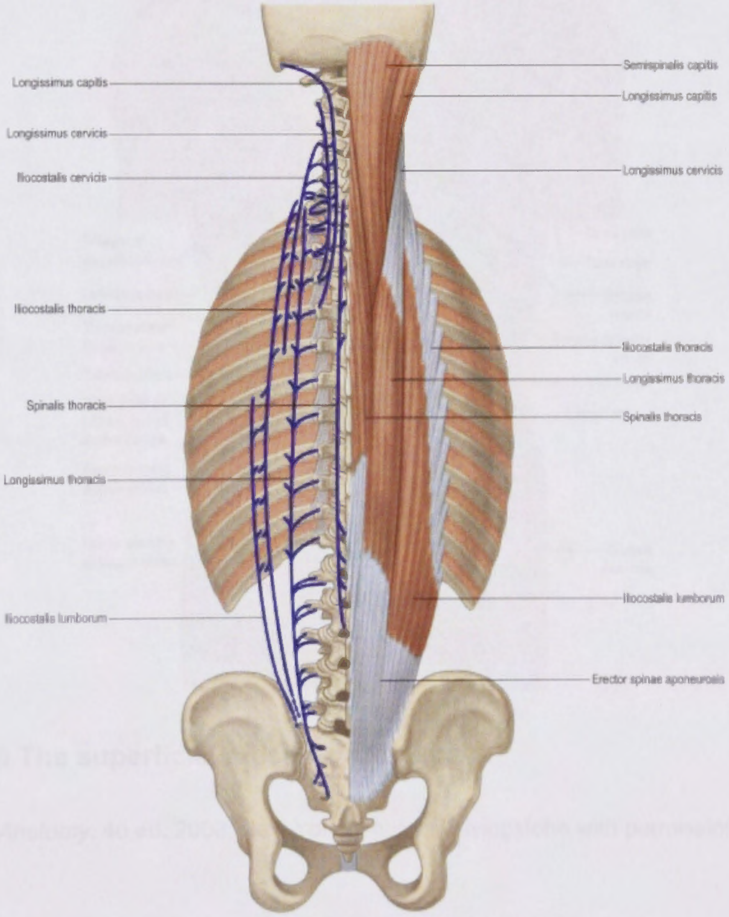

Figure 2.9 The erector spinae

From *Gray's Anatomy*. 40 ed. 2008, New York: Churchill Livingstone with permission

2.3.11.5. Rhomboid major

The rhomboid major arises from the second to the fifth thoracic vertebrae and inserts into the medial border of the scapula. The attachment to the thoracic spinous processes is fascial (aponeurotic) [154]. It acts to retract and elevate the scapula. It lies deep to the trapezius and over the erector spinae and splenii. (Figure 2.10).

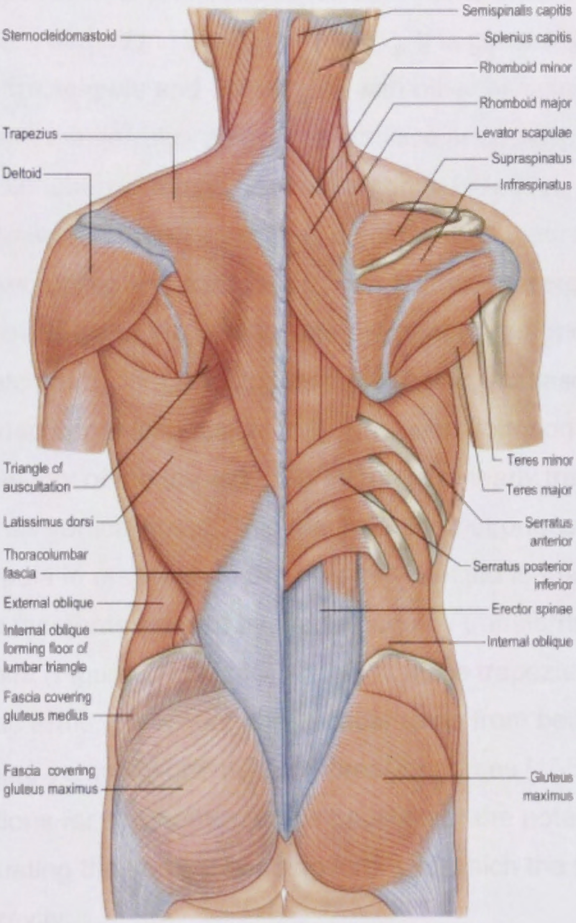

Figure 2.10 The superficial muscles of the back

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2.3.11.6. Trapezius

The trapezius is a large muscle with a number of actions. In the thoracic region it arises from the spinous processes and their supraspinous ligaments. The attachment to the midline in the upper thoracic spine is via a broad triangular or diamond shaped-aponeurosis with its widest point at T3 or T4 [154] (Figure 2.10). The fascicles from C7 and T1 run almost transversely to the acromion and spine of the scapula, and the remaining thoracic fibres insert onto the deltoid tubercle of the scapula in a fanlike distribution [155] (Figure 2.11). It is generally accepted that the trapezius retracts the scapula and cooperates with other muscles such as the levator scapulae and the serratus anterior to stabilise and rotate it upwards around its axis at the deltoid tubercle during arm movements. However, there is some disagreement as to whether the trapezius is a scapular elevator and resistor of downwardly-directed upper limb load [155]. Most textbooks describe trapezius as a scapular elevator because of the vertical arrangement of its upper fibres [106, 110], and the fact that electromyographic studies have shown increases in trapezius activity during loaded upper limb tasks [156]. However, Johnson et al. (1994) have argued that the majority of the trapezius fibres run in a nearly transverse direction with only a few small vertical fibres. This results in their strongest action being not to elevate the scapula in response to downwardly-directed loads through the arms, but to balance the moments exerted by these loads by transferring them to the sternoclavicular joint (Figure 2.11) [155]. In this way the trapezius helps to create a stable 'yoke' for the arms, preventing the cervical spine from being exposed to potentially damaging vertically-oriented compression forces [155]. This may have important implications for the thoracic spine because of the potential role of trapezius in attenuating the vertical bending forces to which the thoracic spine is exposed due to gravity.

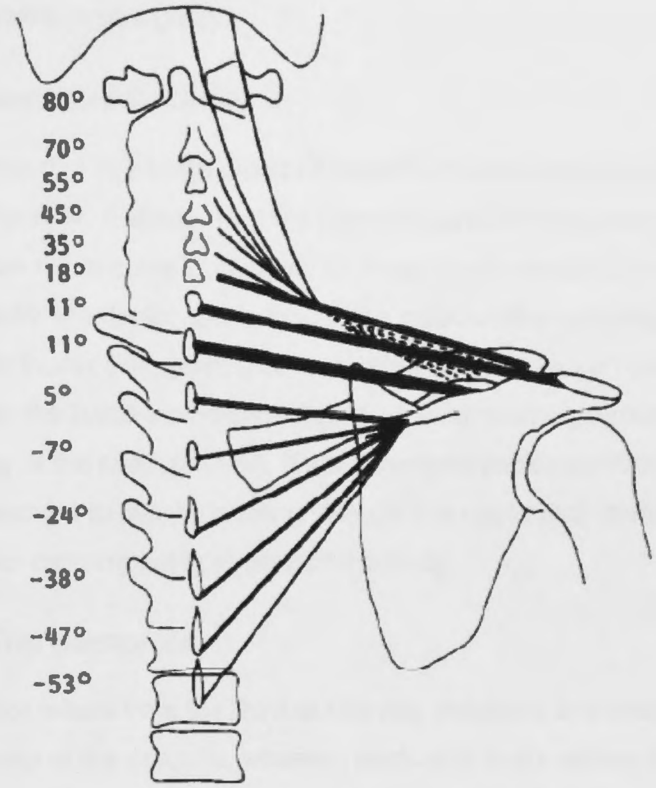

Figure 2.11 Depiction of the trapezius muscle fibres.

Heavier lines indicate fascicles of larger cross-sectional area. Fibre angulation is shown on the left.

From Johnson, G.R., et al., *Anatomy and actions of the trapezius muscle.* Clinical Biomechanics, 1994. 9: p. 44-50 with permission.

2.3.11.7. Latissimus dorsi

The very large and powerful latissimus dorsi (Figure 2.10) arises from an extensive attachment which includes the spinous processes of the lower six thoracic vertebrae to which it attaches via the posterior layer of the thoraco-lumbar fascia (below). It inserts anteriorly on the humerus and, by so doing, is a powerful internal rotator, extensor and adductor of the humerus. Latissimus dorsi attaches to the lumbar spine via the posterior layer of the thoraco-lumbar fascia and is therefore connected to the internal oblique and transversus abdominis via the middle layer of the thoraco-lumbar fascia [157]. It also connects the upper limb to the lower limb because of its continuity with the gluteal muscles, and therefore the lower limb, via the thoraco-lumbar fascia [152].

2.3.11.8. Serratus Anterior

The serratus anterior is a large sheet of muscle which wraps around the chest wall, adhering to it closely. It arises from the upper eight to ten ribs anteriorly and passes beneath the scapula posteriorly to insert into its medial border. Functionally it has three parts: the upper part is thought to stabilise the rotational motion of the scapula on the thorax during shoulder elevation; the middle part provides scapular protraction and the lower part contributes to upward rotation, abduction, and posterior tilting of the scapula [158]. It also prevents backward rotation of the scapula in response to weight-bearing through the upper limb during activities such as push-ups, or carrying loads in front of the body.

2.3.11.9. The pectorals

Pectoralis minor arises from the third to fifth ribs anteriorly and inserts into the coracoid process of the scapula, whereas pectoralis major arises from the clavicle and sternum to attach to the humerus. The main action of pectoralis major is to medially rotate and adduct the humerus while pectoralis minor assists with protraction of the scapula. Decreased pectoralis minor length has been reported to be associated with increased kyphosis [71].

2.3.11.10. The serratus posterior superior and inferior

These muscles have intrigued anatomists because their function in man is uncertain [159, 160]. Serratus posterior superior arises from the spinous processes of C7 to T2/T3 and then descends laterally to insert into the upper borders of the external surfaces of ribs 1-5 just lateral to the rib angles (Figure 2.12). Similarly, serratus posterior inferior arises from the spinous processes of the lower two thoracic and upper two lumbar vertebrae, ascends laterally, and inserts into the inferior surfaces and outer borders of the lower four ribs. Although they have previously been thought to have a respiratory role this has been almost certainly disproven [159, 160]. Of note is that they are much more developed in dogs [159] so perhaps they have role in stabilising the spine in the quadripedal position. Another theory is that they have a proprioceptive role [159]

2.3.11.11. Functional classification

It has been suggested that the muscles of the thorax can be functionally classified into a local and a global system [115]. The local system constitutes the deep 'intrinsic' muscles which control the joints at a segmental level maintaining appropriate 'stiffness' in the joints by acting continuously. It is proposed that these deep muscles, such as the spinotransverse group, control excessive physiological and translational movements. The global system constitutes the larger, more superficial muscles such as the erector spinae and trapezius, which are responsible for generating torque for accelerating and decelerating movements through the available range, as well as stabilising the spine under high load conditions [161]. Conceptualising the movement control of the thoracic spine in this way is helpful when trying to make sense of what is a very complex system.

2.3.12. The thoraco-lumbar fascia

The thoraco-lumbar fascia, so named because of its location, is part of a larger fascial system which, by virtue of its extensive connections, has been called the 'ectoskeleton' – a soft tissue skeleton which complements the bony skeleton by serving as a site for muscle insertion in its own right [162]. The extensive connectivity of the fascial system serves to connect seemingly disparate musculoskeletal areas such as the lower limb and upper limb [163]. Fascia comes in many forms, being highly adapted to the functional requirements of the area it serves, but overall it is made up of connective tissue (collagen and/or elastin) with the dominant cell being the fibroblast. Just two types are of interest in the consideration of the thoraco-lumbar fascia: Areolar fascia, which surrounds skeletal muscle fibres (forming the endo- and epimysia) creating thin films between muscles facilitating movement of one muscle upon another; and deep fascia which is present in the limbs and back and is typically composed of dense connective tissue sheets that have large numbers of closely-packed collagen fibres [163].

The thoraco-lumbar fascia (TLF) is located over the posterior aspect of the spine and covers the deep muscles of the back and trunk from the sacral region to the deep cervical fascia [152] (Figure 2.10). It consists of three layers: the posterior, the middle, and the anterior layers. The middle and anterior layers are reported only to be present in the lumbar spine, terminating superiorly with attachments to the twelfth rib [164] (Figure 2.13). The posterior layer, which will be our focus, has a superficial and deep lamina [164, 165].

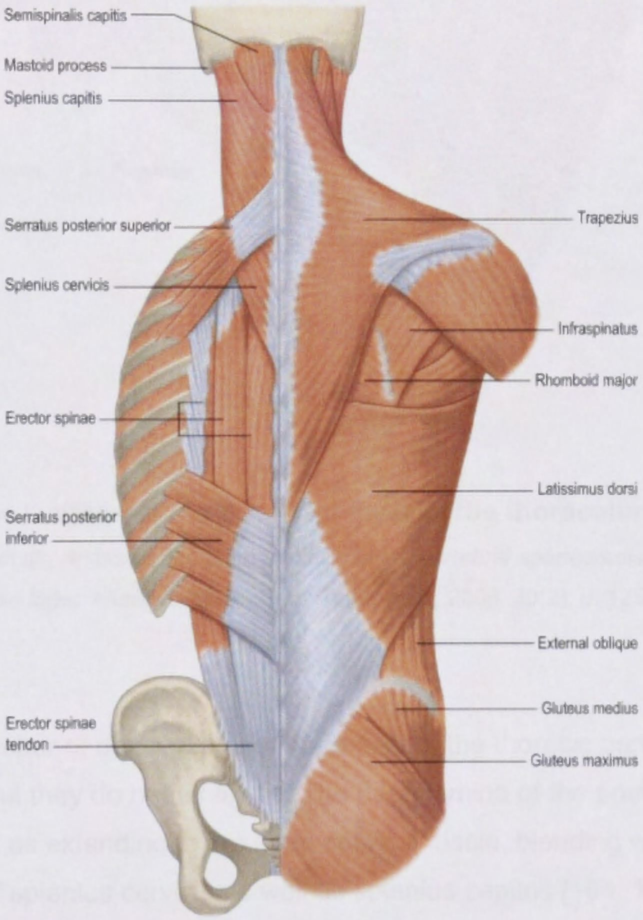

Figure 2.12 Serratus posterior superior and inferior

From *Gray's Anatomy*. 40 ed. 2008, New York: Churchill Livingstone with permission

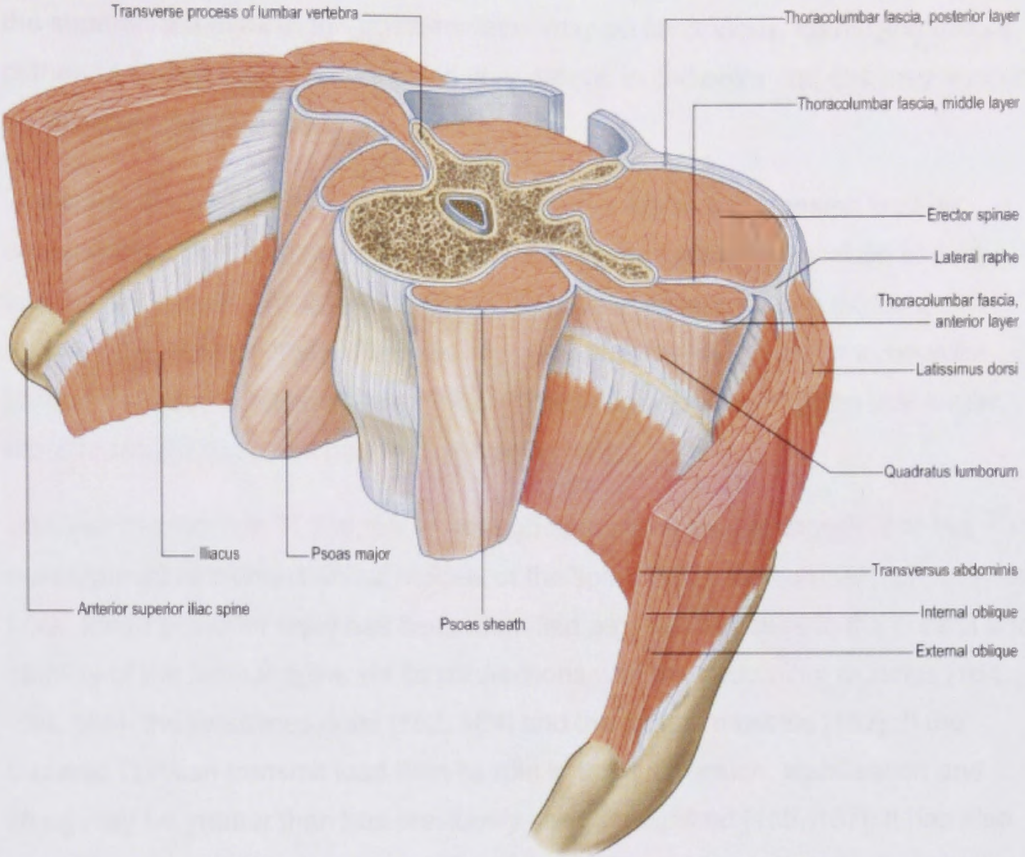

Figure 2.13 The laminae of the posterior layer of the thoracolumbar fascia

From Loukas, M., et al., *Anatomy and biomechanics of the vertebral aponeurosis part of the posterior layer of the thoracolumbar fascia.* Surg Radiol Anat, 2008. 30(2): p. 125-9 with permission.

There are a number of descriptions of the extent of the thoracic part of the thoraco-lumbar fascia but they do not all agree. The deep lamina of the posterior layer has been described as extending to the deep cervical fascia, blending with the aponeuroses of splenius cervicis as well as splenius capitus [164, 165]. However, the superficial layer has been variously described as terminating with the latissimus dorsi aponeurosis at T6 [164], the serratus posterior inferior [152] or more superiorly with the rhomboid aponeurosis [165]. Curiously, in the cervical spine, the deep cervical fascia is described as a separate entity yet it is described as attaching to the midline then splitting to enclose the trapezius muscle. Since the trapezius covers the rhomboid it seems possible that the deep cervical fascia and the superficial lamina of the posterior layer may be continuous. Identifying fascial planes has been described as being very difficult in cadavers and this may account for the discrepancies [166].

The issue of whether the thoracic thoraco-lumbar fascia can transmit load is contentious. The thoracic part of the thoraco-lumbar fascia is described as being thin and incapable of transmitting load [164], the implication being that it is of the areolar type described above. However, other authors have found it to be quite fibrous and able to transmit load [165, 167] with one study identifying that larger, more muscular cadavers had thicker fascia [165].

Whether the thoracic TLF is robust enough to transmit load is important to the development of biomechanical models of the spine [165]. The lumbar TLF, with its thick, fused posterior layer has been identified as a key structure in the control and stability of the lumbar spine via its connections with the abdominal muscles [164, 168, 169], the latissimus dorsi [152, 164] and the gluteal muscles [152]. If the thoracic TLF can transmit load then its role in trunk extension, stabilisation and lifting may be greater than has previously been recognised [165, 167]. It has also been proposed that the posterior layer of the TLF may play a neuro-sensory role [167] which is supported by the finding that it contains free nerve endings as well as two types of mechanoreceptors [170]. Also, more recent findings point to the possibility that fascia may serve as a body-wide mechanosensitive signaling system [171].

2.3.13. Summary

The anatomy of the thoracic spine differs from the other spinal regions in a number of ways. It is part of the thorax and therefore is influenced by its costal attachments. It is shaped differently to allow more rotation than other regions for which the shape of the discs has adapted. The vertebral bodies are anteriorly wedged to accommodate the curvature necessary for spinal balance. The intervertebral discs are thinner and rounder than the cervical and lumbar discs. The musculature and associated fascia are layered and complex and poorly-understood compared to the lumbar region. It is important, therefore, to appreciate these differences when extrapolating findings from other spinal regions, in particular the lumbar spine, about which there has been vastly more investigation.

2.4. Kinematics and biomechanics of the thoracic spine

Biomechanics is the application of mechanical principles to living organisms; and kinematics is the branch of biomechanics concerned with motion without reference to force or mass [111]. In this section, the kinematics of the thorax and the thoracic spine will be discussed in terms of how the vertebrae interact with each other, and with the ribs, during thoracic spine movements. The biomechanics of the thoracic spine will be discussed in terms of how the spine and thoracic vertebrae are loaded and how that load is managed. Finally, the biomechanical consequences of hyperkyphosis will be discussed.

2.4.1. Terminology

Describing kinematic concepts can be difficult so, in order to clarify the following descriptions, some basic definitions of terms used are included here. The terminology is adapted form Panjabi, Brand and White (1976) [48].

The planes and axes are described by Figure 2.14. The axes run perpendicular to the planes so that flexion and extension takes place in the sagittal plane while rotating about the transverse axis; side flexion takes place in the coronal plane while rotating about the sagittal axis and and axial rotation takes place in the transverse plane while rotating about the coronal axis.

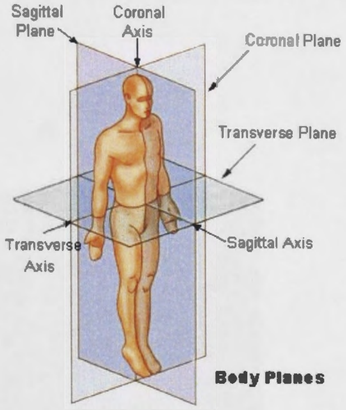

Figure 2.14 The three body planes and axes

Adapted from http://commons.wikimedia.org/wiki/File:TelesneRavnine.jpg

Motion: The change of position of a rigid body in space with time. This motion may be pure translation, pure rotation, or both which is usually the case.

Translation: Motion of a rigid body in which every part of the body moves along a parallel path.

Rotation: The motion of a rigid body which causes a straight line somewhere within that body to remain motionless. This line is the axis of rotation.

Coupling: When translation along or rotation about one axis is consistently associated with another translation along or rotation about a second axis.

2.4.2. Kinematics of the thoracic spine

The shape and orientation of the thoracic zygapophyseal joints facilitate multiaxial movement but while lateral flexion and rotation are facilitated, flexion and extension are relatively limited (White 1969). During flexion of the trunk the thoracic vertebrae rotate about the transverse axis with slight anterior translation and compression [48]. The inferior (forward facing) facets of the zygapophyseal joints glide superiorly in flexion and inferiorly in extension [115] (Figure 2.15). Although the ribs are capable of moving without forcing concomitant movements of rib cage [172], the relative movement of each influences, and is influenced by, the costovertebral joints [115].

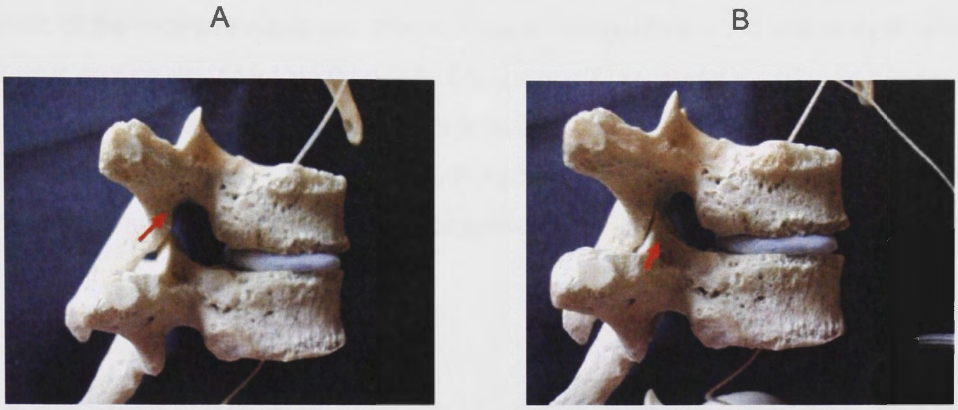

Figure 2.15 Relative movement of the zygapophyseal joints during flexion and extension in the thoracic spine. A. Flexion – inferior facets glide superiorly; B Extension – superior facets glide superiorly.

The costovertebral joints in the adult thorax are fully formed and significantly limit the degree of thoracic movement [173]. The thorax becomes stiffer with increasing age and in old women the costal cartilages can even become partially ossified [174]. So, although it can be mobile, the thorax can also be equally stiff or stiffer than the vertebral joints [115]. In the absence of adequate means of performing kinematic measurement of rib and costovertebral movement, Lee has used clinical observation and analysis to describe the kinematics of the ribs in relation to spinal movements [115]. In the stiff thorax the normal kinematics of the costovertebral joints are reversed so that the costovertebral movement is exhausted before that of the vertebrae forcing the rib tubercle to roll and glide in the opposite direction to normal during terminal flexion [115]. This alteration of the normal costovertebral kinematics may be partly responsible for the high incidence of costovertebral joint degeneration which has been detected in the cadavers of older people [132].

Spinal coupled motion is the rotation or translation of a vertebral body about or along one axis which is consistently associated with the main translation or rotation about another axis [48]. Sagittal plane movement i.e. flexion and extension, is the purest of the movements in the thoracic spine being associated with only minimal anterior and posterior translation [48, 49]. Lateral flexion and rotation however, are coupled in the thoracic spine but there is controversy as to the direction in which this takes place [175]. A number of authors have investigated coupling between side flexion and rotation in the thoracic spine with varying results [48, 49, 176-179].

Figure 2.16 Relative movement of the zygapophyseal joints during rotation to the left. A. Rotation with ipsilateral lateral flexion; B. Rotation with contralateral lateral flexion

Panjabi and Brand [48] examined coupling behavior of the thoracic spine *in vitro.* They found that contralateral rotation accompanied side flexion and that both ipsilateral and contralateral side flexion accompanied rotation (Figure 2.16).

Willems et al. [49] and Gregerson and Lucus [176] studied coupling of thoracic spine movements *in vivo*. Willems et al. used 3 dimensional electromagnetic tracking and found that in the middle and lower thoracic vertebrae coupling was predominantly (but not always) ipsilateral but in the upper thoracic vertebrae (T1 to T4) the coupling direction was much more variable. Their 30 male and 30 female subjects were all aged between 18 and 24 years and no gender differences were detected. Gregerson and Lucus (1967) also used a young cohort (7 males aged between 20 and 26). Their limited sample number is unsurprising given that their method of measurement required the insertion of Steinman pins into the spinous processes of their subjects. They, like Willems et al., also reported ipsilateral rotation with side flexion but did not assess the coupling behaviour if rotation was the initiating movement. This direct measurement technique, although very invasive, has the advantage of removing the complication of skin movement from the equation.

Mathematical models have suggested that the coupling behaviour is ipsilateral [177, 178] and that the coupling behaviour is more profound in more kyphosed postures [178]. A recent *in vivo* study found that rotation decreased in flexion but that in flexed positions the percentage of lateral flexion as a function of the concommitent rotation increased from 8.9% to 23.2% [180].

Although sagittal plane movements should not be accompanied by rotation it is suggested that zygapophyseal asymmetry, which is common in the thoracic spine, will result in rotation to the left during flexion [142]. This assertion has not been confirmed *in vivo*.

The reason for the coupling of rotation and side flexion has been ascribed to the shape of the zygapophyseal joints but Lee has proposed a different model [115]. It is suggested that during side flexion rib movement is arrested before the vertebrae, thereby forcing the vertebrae to continue to move on stationary ribs. The result is that the ribs at the corresponding right and left costovertebral joints rotate in opposite directions. This causes the vertebrae to rotate in the direction of lateral flexion (ipsilaterally) but only at the end of range. This theoretical construct would accord with the kinematic findings of the *in vivo* studies [49, 176, 180] but not the in vitro studies of Panjabi et al. who examined the motion segments (see 2.2.3) without an intact thorax [48]. In spines of stillborn babies, in which the costovertebral joints are unformed, rotation and lateral flexion are uncoupled [181] supporting Lee's theory that the kinematics of the costovertebral joint bring about the coupling.

In summary, although normal sagittal plane movement should not involve lateral flexion or rotation, the effect of asymmetry and age has not been investigated *in vivo.* Stiffness of the thoracic cage reverses the kinematics of the costovertebral joints during flexion and extension movements. The costovertebral joints would seem to have a fundamental role in the coupling behaviour of lateral flexion and rotation in the adult thoracic spine. In view of the fact that this coupling behaviour is significantly altered by increased flexion, the kinematics of the thoracic spine may be dramatically altered by hyperkyphosis. This has yet to be investigated.

2.4.3. Biomechanics – how the vertebrae resist loading

Having discussed the movement possible at the thoracic spine and how it is achieved kinematically, the discussion will now be directed at how stability is achieved. A fundamental function of the spine is to efficiently support the upper body during all activities by transmitting compressive and shear forces to the lower body [182]. Stability is therefore an essential function of the spine and a number of researchers have speculated as to how this force sharing is achieved [149, 173, 183-192]. Although most spinal research is focussed on the lumbar spine some of the concepts may be judiciously applied to the thoracic spine.

In the 1960s Lucus and Bressler published a very influential report in which they concluded that the axially loaded ligamentous spine† is essential unstable being able to bear only a fraction of the force to which it may reasonably be expected to be subjected during normal daily activities without buckling [183]. This oft cited paper has been the inspiration for a number of theories aimed at solving the puzzle of how the spine (specifically the lumbar spine) manages to remain stable in the face of compression loads of up to 18,000 Newtons during activities such as competitive power lifting [182] when the ligamentous spine in vitro buckles under compressive loads as low as 2 kg (approximately 20N) [183].

In view of the discrepancy between these *in vitro* findings and the resilience of the spine *in vivo,* it is clear that the stability of the spine *in vivo* must be dependent on

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† Cadaveric preparation of the whole spine with vertebrae, discs and ligaments but ribs and muscles removed.

extrinsic structures [184]. In the thoracic spine, these 'extrinsic structures' potentially include the ribs and their articulations [193] and the supporting muscles [185, 192], the thorax and abdomen via intra-compartmental pressures [184] and possibly the thoraco-lumbar fascia [165]. The differential effects of the various intrinsic and extrinsic spinal and thoracic structures are discussed individually below but the biomechanical theories which underpin the aforementioned dynamic mechanisms are discussed first.

2.4.3.1. The spine as a flexible rod

The ligamentous spine can be modelled as as a flexible rod which will buckle if sufficient axial load is applied [183, 185]. According to Euler (Swiss mathematician, 1707-1783) the critical load at which the rod will buckle is associated with its length, moment of inertia and whether the ends are fixed [185]. If one end of the rod is not fixed the critical load is reduced by a factor of 16 [183]. Weakness of the proximal musculature in the shoulder girdle has been likened to the unclamping of one end of the spinal flexible rod [185]. The trapezius muscle with its transversly oriented fibres in the upper thoracic spine has been reported to transmit forces generated by the upper limb horizontally to the sternoclaviclular joint via its insertion onto the scapula [155]. This type of force transmission could feasibly create a fixation for the upper thoracic spine, increasing its stiffness and the critical load thereby enabling it to resist more load before 'buckling'.

2.4.3.2. Intra-abdominal and intra-thoracic pressure

Of course modelling the thoracic spine as a simple flexible rod is too simplistic. It has long been known that abdominal contraction accompanies trunk extension [194] and that intra-abdominal and intra-thoracic pressure increases with increasing load [184]. It is generally accepted that a rise in intra-abdominal and intra-thoracic pressure increases the stiffness of the spine and by creating stiff cylindrical units unloads the spine by up to 50% [184]. It has been suggested that intra-abdominal pressure is merely an artefact of trunk muscle activation (Marras and Mirka, 1996). However early experiments showed that the wearing an abdominal brace during a lifting task attenuated the degree of muscular contraction while maintaining the intra-abdominal pressure constant [184]. Thus the utility of the raised pressure rather than the muscle action was demonstrated.

2.4.3.3. The effect of the erector spinae

The role of the erector spinae as a stabiliser and extensor of the spine is controversial [187, 190]. The spine and the individual vertebrae are loaded in two ways: by the tensile forces from muscles which act upon them, and by the forces and moments acting upon them from above or below due to gravity, superincumbent weight and extrinsic load [18]. Because the thoracic spine is concave anteriorly, the centre of gravity is anterior to the thoracic vertebrae [111]. As a result, the thoracic vertebrae in normal upright standing or unsupported sitting, are constantly subjected to flexion moments [111] which must be balanced by extension activity in the erector spinae [18, 185, 186]. The effect of increasing the thoracic curve or lifting/carrying weight anteriorly, is to significantly increase the flexion moment acting on the thoracic spine [111, 195]. Because the erector spinae traverse the spine very close to the instantaneous centres of rotation for extension, they have very short moment arms [92, 111]. In the thoracic spine, maximum compression forces are borne by T7 and T8 [195, 196]. The maximum force that the T7/8 vertebrae can withstand has been reported to be 1458N [197]. The tensile forces that would be required to effect spinal extension under even small anterior loads would theoretically exceed this limit and cause vertebral destruction and spinal buckling [188, 198, 199]. But this is not seen *in vivo*. Thus a number of mechanisms have been proposed which may assist the extensor muscles during loaded extension to be able to withstand greater loads.

2.4.3.4. Intra-compartmental pressure and extension moment production

If the hydrostatic pressure created within the thorax and abdomen was capable of producing an extensor moment, the force generating requirement of the erector spinae would be reduced. It was originally suggested that raised intra-abdominal pressure might itself generate an extensor moment [194, 200] but this has been largely discounted because of the contradictory role of the abdominal muscles in their roles as flexors [189, 201]. However, when the trunk is modelled so that intra-abdominal pressure is generated by muscles acting in a transverse direction rather than a vertical direction, the net extensor torque is positive [202, 203]. In support of this theory, EMG recordings of the abdominals during extension have shown that it is the transversus abdominis and to a lesser extent the internal obliques which are most active [200, 204]. Conversely, in opposition to this theory are the following findings: erector spinae activity is not reduced when intra-abdominal pressure is increased [203]; eccentric extension results in a reduction in intra-abdominal pressure [205]; and the addition of an anteriorly positioned load in standing during a valsalva manoeuvre results in a decrease in intra-abdominal pressure [206]. If the intra-abdominal pressure were responsible for increasing extensor moment then it would have increased in all of these circumstances, not decreased [207]. It is generally concluded that the increases in intra-abdominal and intra-thoracic pressures which accompany extension tasks are an important mechanism for stiffening the trunk and unloading the spine, rather than creating extensor torque [184, 203, 207]

2.4.3.5. The thoraco-lumbar fascia

The thoraco-lumbar fascia (TLF), which has been described previously, is continuous longitudinally from the occiput to the sacrum and illium where it blends with the gluteal muscles [152]. The TLF has the largest moment arm of all the posterior structures by virtue of the fact that it lies most distal to the vertebrae [149]. This fact has led to speculation as to its role in extension force production [149, 187, 208]. The fibres of the TLF are obliquely orientated. When subjected to stretch their fibre angle becomes more vertical thereby accentuating the elastic recoil properties of the fascia and potentially resulting in an extensor moment being generated passively [149]. This theory was investigated via a mathematical model and the extension forces exerted by the TLF were shown to be negligible [149]. However, this model was constructed prior to the discovery that the thoraco-lumbar fascia is continuous with the gluteal and hamstring muscles [152]. These connections make the tensioning of the TLF by the gluteal and hamstring muscle contraction theoretically possible [152]. These newer findings suggest the possibility that the TLF may assist with extension of the lumbar spine but this has not been confirmed experimentally. In cadavers the TLF in the thoracic spine has been found to be thinner and less able to transmit force than in the lumbar spine [209]. However, a recent study reported that the force transmitting capabilities of the TLF are greater in more heavily built cadavers [165]. It is possible therefore that, in younger people with robust healthy tissues, the TLF may have a role in assisting with extension of the thoracic spine.

2.4.3.6. Hydraulic amplification

The TLF may also enhance the extension of the erector spinae by producing hydraulic pressure [187]. Gravetovsky and Farfan (1986) suggested that the increase in cross sectional area which accompanies contraction of the lumbar erector spinae produces tension in the overlying TLF causing it to pull on the spinous processes and induce extension [187]. They called this ‘hydraulic amplification’. Hukins et al. (1990) interpreted the concept of ‘hydraulic amplification’ differently [208]. They submitted a mathematical proof which showed that by restricting the radial expansion which accompanied contraction of the erector spinae, the TLF, was able to create hydrostatic pressure within the compartment formed by the middle and posterior layers of the TLF, causing the erector spinae to function hydraulically – much like two long balloons. They calculated that this mechanism may increase the efficiency of the erector spinae by up to 30% [208]. The application of this theory to the thoracic spine has not previously been discussed.

2.4.3.7. The spine as an arch

At the commencement of this section it was suggested that the erector spinae muscles are ill-suited to the task of extending the spine because of their short moment arms. However the validity of this conclusion depends on the model used to characterise the spine. Aspden (1989) suggested that the spine should be modelled as an arch rather than a flexible rod. Modelling the spine as a masonary arch, using plasticity theory* rather than elasticticity theory*, results in critical loads which are more than nine times lower [190]. Using this model a hyperkyphotic posture would be more stable and the wedge shape of the thoracic vertebrae begins to emerge as an important adaptation designed for stability. This theory is supported by the finding that young athletes are significantly more kyphosed than their sedentary peers [210] and by the finding that non-athletic men have smaller thoracic kyphoses and lumbar lordoses than their athletic counterparts [211]. Aspden modelled the lumbar spine and not the thoracic spine but theoretically, as long as the arch is sufficiently loaded (by truncal co-contraction, for example), the same principle would apply to the thoracic spine. The intrinsic structures which confer stability to the thoracic spine and their relative contributions will now be discussed.

2.4.3.8. The zygapophyseal joints

The effect of the orientation of the zygapophyseal joints has been discussed above. Although the zygapophyseal joints function to limit flexion, Panjabi et al. found that the costovertebral joint was capable of withstanding flexion forces in the

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* Plasticity and elasticity theory describe how a solid responds to an applied stress:

Elasticity theory assumes that when an applied stress is removed, the material returns to its undeformed state.

Plasticity theory assumes that when the stress is greater than the yield stress, the material behaves plastically and does not return to its previous state 190. Aspden, R.M., *The spine as an arch. A new mathematical model.* Spine (Phila Pa 1976), 1989. **14**(3): p. 266-74..

absence of the zygapophyseal joint, but without the costovertebral joint stability was lost [212].

2.4.3.9. The thorax including the costovertebral Joints

It is logical to think that the thoracic rib cage is primarily responsible for stabilising the thoracic spine in the sagittal plane. An early computer-simulated mathematical analysis showed that the rib cage enhances the stability of the thoracic spine by increasing stiffness in flexion by 27% and in extension by 132% [213]. In a subsequent human cadaveric study Oda et al (2002) found that after discectomy the removal of the rib head increased the flexion/extension range by 81% [173] indicating that the costovertebral joints provide a significant amount of stability to the thoracic spine. Their specimens however did not have an intact sternal attachment. More recently another cadaveric study showed that the ribs and sternum enhance the stability of the thoracic spine by 40% but the authors did not evaluate or isolate the contribution of the costovertebral joints [193]. The high incidence of costovertebral joint hyperostosis in elderly cadavers [132] indicates that the costovertebral joints probably do have a significant stablising role therefore supporting the *in vitro* findings. Finite element modeling has predicted that the ribs and their attachments confer significant stability on the thoracic spine and may reduce its mean flexibility by between 23% and 47% [214].

2.4.3.10. The intervertebral discs

The role of the intervertebral disc is fundamental to the stability of the spine. In both canine and human models removal of the discs resulted in more sagittal rotation than removal of the ribs, sternum and costovertebral joints [173, 191, 215]. In contrast to the lumbar and cervical discs, the thoracic disc is thin and stiff [121]. It is thought that this feature of the thoracic disc reduces the movement possible at the thoracic joints thereby allowing the thorax to enjoy a relatively stable and immobile anchorage. It is clear that removal of the disc would destabilise the spine and this was demonstrated in one of the dissection studies described above where removal of the disc increased the range of motion in the sagittal plane of a single the spinal segment by 193% [173]. Thus the disc is an important stabiliser of the thoracic spine.

2.4.3.11. The ligaments

In most joints the ligaments play a major role in maintaining the stability and integrity of the joint [198]. In the spine however, apart from the costovertebral ligaments which attach the ribs firmly to the vertebrae, the ligaments have been reported to play a relatively minor role in the mechanical limitation of movement [111, 212]. It has been suggested , however, that the spinal ligaments may have a proprioceptive role triggering protective muscular contraction in response to damaging loads [198]. This mechanism was detected in a study of the supraspinous ligament in which a relationship was found between EMG discharges from the multifidus muscle and stress to the ligament [198]. Thus, although the ligaments may not be mechanically protective, they appear to have a role in the modulation of muscular efforts to stabilise the spine.

2.4.3.12. The muscles

It is known that the trunk muscles are fundamentally important to the stability of the lumbar spine [198, 216]. The role of the trunk muscles with respect to thoracic spine stability is not completely understood. It may be reasonable to speculate that, in view of the relative stiffness of the thorax that the muscular contribution may be diminished in comparison to other areas. However, it has already been established that the thoracic spine is mobile, even into older age, and therefore muscular effort must be involved in stabilising the thoracic spine during tasks such as lifting or even just remaining upright. Unfortunately, measurement of the activity of the thoracic erector spinae muscles is difficult because they are covered by more superficial muscle groups [154] but it is almost certain that these muscles, along with the abdominal muscles, do play a significant role in stabilizing the spine during dynamic activities. The stabilizing role of the erector spinae muscles in the thoracic spine was quantified in a finite element model of the effect of erector spinae muscular weakness in young boys with muscular dystrophy [192]. The model calculated that a reduction of 50% in the force generating potential of the erector spinae muscles altered the kyphotic angle from 35 to 110 degrees [192]. Although the erector spinae play a crucial role in stabilizing the spine [217], trunk stability almost certainly relies on co-contraction of the extensor and flexor muscle groups

[218]. In a study which measured the responses to sagittal perturbations in young men with and without co-contracted or 'preloaded' trunk muscles it was found that the trunk increases its stiffness and ability to withstand flexion moments by co-contracting the trunk muscles [218]. Evidence of truncal co-contraction was also detected in the aforementioned finite element model of the thoracic spine which calculated that a decrease in thoracic erector spinae strength and subsequent increased kyphotic deformity resulted in an increase in rectus abdominis and internal oblique muscle activity [192]. Thus the muscles of the trunk have been described as 'acting not only as force generators, but also as stabilizing springs similar to guy wires spanning a bending mast' [219]. The effect of this stabilising system is not without cost. Co-contraction has been estimated to increase compression forces acting on the lumbar spine during lifting tasks by as much as 45%, and shear forces by as much as 70% [220]. In the thoracic spine the compression force is reported to be the dominant force vector [195]. During lifting tasks the forces generated by the extensors have been reported to be as much as 47% greater than the applied lifting moment in order to offset the flexor antagonism needed to stabilise the spine for the task [220]. Thus the tensile forces that result from muscle contraction are a major component in the consideration of spinal forces.

The stabilising role of the superficial muscles of the back has received little attention in the literature. However, bearing in mind their size and extent, it seems likely that they, like the abdominal muscles are implicated in stabilising the thoracic spine. A potential role of the trapezius muscle was mentioned previously under 'the spine as a flexible rod' (2.4.3.1).

2.4.3.13. The biomechanical consequences of hyperkyphosis

The older thoracic spine is characterized by a loss of flexibility and strength as well as increased kyphosis. The effects of increased kyphosis on the biomechanics of the spine are numerous. A recent biomechanical study investigated the effect of kyphotic angle on the muscle activity and resultant forces in the thoracic spine [195]. In this study a cohort of elderly people were dichotomised into low and high kyphosis groups and investigated in terms of electromyography (EMG) and anatomical configuration. With these data the authors were able to model the forces to which the spine was subjected using an optimization approach (maximization of physiologic efficiency). The study showed that the flexion moments were significantly greater in the high kyphosis group compared to the low kyphosis group. These high moments were associated with higher compression forces in the mid and lower thoracic segments, peaking at T8. The compression and shear forces resulting from muscle contraction were also significantly higher in the high kyphosis group, with compression being the dominant vector. These increased stresses secondary to hyperkyphosis have been implicated in the aetiology of osteoporotic fracture [92].

2.4.4. Summary

The kinematics and biomechanics of the thoracic spine have been sparsley investigated and as yet are only partially understood. The role of the rib articulations emerges as an important factor in determining the kinematics of the spine and these are undoubtedly influenced by an increase in the kyphotic curve. The inherent instability of the ligamentous spine modelled as a flexible rod has been a common theme in biomechanical research but the inherent stability of the spine modelled as an arch may provide a better model for the thoracic spine potentially explaining the utility of the wedged vertebrae as an adaptation designed for stability. The mechanisms by which the thoracic spine manages the apparent inefficiency of the erector spinae are unknown but there are a number of theories which would benefit from investigation. Finally, hyperkyphosis would seem to increase the load on the thoracic spine, particularly at the apex of the curve where the forces are concentrated. Theoretically, as the extent of the curve increases so do the compression and shear forces which would eventually lead to degeneration and failure of a number of key thoracic structures.

2.5. Aetiology

Age-related hyperkyphosis has been defined as "an exaggerated anterior curvature in the thoracic spine that occurs commonly with advanced age" [221]. There are various potential causes of age-related hyperkyphosis including vertebral wedge deformity, disc degeneration, muscle weakness and ligamentous changes. Juvenile kyphosis, or Scheuermann's disease, is a major cause of hyperkyphosis in adolescents. This section will be divided into age-related (as defined above) and non age-related causes of kyphosis with the major emphasis being on the former.

2.5.1. Age-related causes

In adults, hyperkyphosis is reportedly caused by osteoporosis [17, 34, 63, 84, 222-225], thoracic vertebral remodelling deformities [226, 227], intervertebral disc disease [21, 228, 229], age-related changes in muscle [93, 112] and ligamentous changes [150, 230, 231]. The prevalence of diffuse idiopathic skeletal hyperostosis (DISH) increases significantly with age [232] and the influence of heredity may be a significant factor [19].

2.5.1.1. Vertebral wedge deformity – osteoporosis or remodelling?

Osteoporosis is widely considered to cause hyperkyphosis by increasing the frequency of osteoporotic wedge fractures of the thoracic spine. The majority (>85%) of the kyphotic curve in older adults is explained by the shape of the vertebrae and discs [233]. The relative contribution of the vertebrae to this has been reported to be between 42% [112] and 78% [1]. A decline in bone mineral density occurs at around 50 years of age but there is evidence that bone mineral mass and trabecular bone volume can begin to decline well before that time [234]. Although bone is continually being remodelled throughout life by a process of osteoclastic excavation and osteoblastic reformation, with increasing age the amount of bone lost becomes greater than that being made resulting in a negative balance or an overall loss [113]. This situation is further exacerbated by the decline in sex hormones. In trabecular bone the amount of bone lost in men and women is similar but the mode of bone loss is different [235]. Men and women begin with the same bone density at the completion of puberty but men have larger bones which are also stronger - as a result of their size rather than their density [113]. In men, aging results in a reduction in bone formation leading to trabecular thinning [235]. However, in women, there is an increase in bone resorption due to oestrogen deficiency, which results in loss of whole trabeculae leading to loss of trabecular connectivity [235]. Vertebral body strength is compromised more by loss of connectivity than by thinning so women tend to lose bone strength in their vertebrae before men, and this results in a higher incidence of vertebral and non-vertebral fractures [236]. The tendency for a vertebra to collapse as a result of this thinning or loss of connectivity depends on the nature and extent of the forces applied. A pre-existing increase in thoracic kyphosis will predispose the thoracic vertebrae to collapse as a result of age-related changes in vertebral strength [92, 237].

Vertebral fractures form an integral component of the osteoporotic syndrome and their presence is sometimes included in its definition [238]. The most prevalent fracture attributed to osteoporosis is the vertebral fracture, whereas hip fractures reportedly only occur in the most severely osteoporotic patients [239]. However, the presence of wedge deformity in the thoracic spine does not necessarily imply that a vertebra has been fractured [226, 227]. There are two clear types of vertebral compression fracture: those that are symptomatic and those that are not [101]. The symptomatic or ‘incident’ fractures are characterized by pain which is often intense and long lasting [101]. The asymptomatic, or ‘prevalent’, fractures are those which are found by chance on X-ray with the diagnosis being based on a significant reduction of anterior vertebral height [60, 240]. These are also called ‘silent’ fractures because they are not associated with any pain or loss of function [93, 241-243]. This curious disparity in symptoms associated with the same diagnosis suggests that the two types of ‘fracture’ may have different underlying mechanisms.

Importantly, the literature indicates that there is some confusion about what constitutes a fractured vertebra as opposed to a remodelled vertebra [226]. According to the 'Hueter-Volkmann Law', longitudinal growth of bone is retarded by increased mechanical compression and accelerated by reduced loading [244]. Vertebral wedging is therefore a normal response to the adoption of an upright posture [245].

Since its publication in 1993, the most common method of diagnosing vertebral fracture due to osteoporosis is based on Genant's semiquantative criteria [240]. In fact, because fractures identified in this way are frequently asymptomatic, they have often been used as the first indication of osteoporosis [246]. Genant's criteria stipulate that a 20% reduction in anterior vertebral height compared to the posterior height seen on lateral X-ray constitutes a grade 1 fracture. However, Genant also stipulated that the diagnosis of fracture should not rely solely on the morphometric features. Other features such as end-plate deformities and buckling of cortices, unparallel end-plates and loss of vertical continuity should be included in making the diagnosis. However, Genant's morphometric criteria alone have come to be used by many research groups to identify and quantify vertebral fracture and, by extension, the existence of osteoporosis [21, 126, 223, 247].

The true prevalence of osteoporotic fractures may thus be overestimated because morphometric changes are incorrectly attributed to fracture rather than remodelling [226]. Kleerkoper and Nelson (1992) found that only 25% of radiologically-diagnosed 'fractured' vertebrae could be confirmed as such with radionuclide bone scan and concluded that the majority of vertebrae labelled as 'fractured' were, in fact, simply deformed due to mechanical stresses over time. They urged caution when interpreting morphological changes as 'fractures' [226]. Another study found that true osteoporotic fractures were associated with both anterior and mid-body height reductions as compared with non-fracture wedge deformations which were more uniformly wedged from front to back [227].This finding has recently been verified in a study which used mid-vertebral heights to differentiate wedging due to osteoporosis and other causes [248]. Genant's criteria have recently been criticised for lack of specificity because they were unable to distinguish wedge deformity in vertebrae with increased bone mineral density from those with decreased bone mineral density whereas other algorithm-based morphometric methods could [249-251]. It has been suggested that a threshold of 30% rather than 20% reduction of anterior vertebral height compared to posterior vertebral height better differentiates between fracture and non-fracture wedge deformity, particularly at the apex of the kyphotic curve between T6 and T9 where bending forces are highest [249]

Thus, although osteoporosis undoubtedly causes vertebral wedge deformity, vertebral wedge deformity is not necessarily caused by osteoporosis. Bone mineral density is strongly correlated with vertebral bone strength, but measures of bone mineral density remain an incomplete predictor of 'fracture' risk, indicating that other factors must be involved [252]. Loss of horizontal trabeculae, with concomitant decrease in architectural strength, can occur without loss of bone mineral density [253]. This remodelling, although also present in osteoporosis, may be the result of alterations in people's patterns of day to day activity, particularly a reduction in speed and vigour, a condition which is associated with aging and debilitation [254].

2.5.1.2. Bony remodelling or osteoarthritis

Wedged 'degenerative' vertebrae have been described by some authors as osteoarthritic because they are associated with osteophytes, increased bone density and degenerative disc disease [227, 255]. Osteoporosis and osteoarthritis have been reported to be mutually antagonistic and it is therefore very rare for them to exist together [256, 257]. Osteoarthritic vertebrae have an increased concentration of osteocalcia and local growth factors which protect against osteoporotic fracture [257]. In contrast, a recent study reported finding that there were large numbers of osteoarthritic women who did have 'fractured vertebrae' which they identified by morphometric criteria [255]. The authors concluded that women with osteoarthritis did not have a reduced risk of vertebral fracture. However, another way to interpret these findings could be that non-fracture deformities were mislabelled as fractures because of misinterpretation of Genant's criteria, a problem that has long been anticipated by leaders in the field [226, 240].

The mechanism by which the deformation of the thoracic vertebrae may occur is not clear. It is known that vertebral motion segments (two vertebrae with an intervening disc) deform under compression in a non-linear fashion described as 'creep' [258]. Visco-elastic deformation of the end-plates appears to play a major role in 'creep' deformation of the vertebral bodies [259], and the discs themselves may play a role in the changes in vertebral morphology [260]. A study of the microarchitectural changes in vertebral bone showed that the mineral density of bone adjacent to osteophytes was selectively diminished indicating that remodelling may be the result of a redistribution of bone minerals to areas where the forces are greatest such as in the anterior aspect of the thoracic vertebral body [261].

In summary, it has long been understood that wedge deformity does not equate to fracture but this has not prevented clinicians and researchers from misidentifying remodelled vertebrae in the older population as having been fractured. The prevalence of vertebral osteoporotic fracture, particularly at the apex of the thoracic curve, may be overestimated by up to 75% as a result of this misunderstanding [226]. The mechanisms which underpin vertebral remodelling are not well understood but they are believed to be a response to mechanical stimulus.

2.5.1.3. Degenerative disc disease

There seems little doubt that degenerative discs in the thoracic spine contribute significantly to hyperkyphosis [19]. This is evident in the findings of two very large studies of kyphosis in older people [21, 229]. A study of 1407 community-dwelling adults in the US found that disc degeneration, rather than vertebral fracture, was more common in people with the most severe hyperkyphotic deformity [21]. Similarly, a European study found that disc space narrowing in older women was more closely related to risk of 'fracture' (wedge deformity) than decreased bone mineral density [229].

Although disc wedging has been shown to contribute to the kyphotic curve directly [233], the influence of the degenerated disc is not confined to its shape. Degeneration of the disc can alter the distribution of stresses on the vertebral body thereby causing structural changes [260, 262]. For the most part our knowledge of the thoracic intervertebral disc is extrapolated from research involving the larger lumbar disc, but thoracic discs differ from lumbar discs in several ways. Importantly, the thoracic disc behaves differently to lumbar discs under a compression load because it is thinner and stiffer [263]. Lumbar discs, which are thicker and have a larger nucleus, behave more like a fluid-filled bag when subjected to asymmetrical compression. They deliver a uniform stress, distributed across the entire end-plate in response to compression. The thoracic disc, especially when degenerated, behaves more like a solid and so asymmetrical compression loading results in shear stresses which are perpendicular to the end-plate [263]. The stresses are then transferred to the vertebral bodies and may explain, at least in part, the degree of wedge deformity which is seen in the thoracic spine.

The effect of disc derangement on vertebral morphometry was recently demonstrated in a baboon model. The effect of nucleotomy on baboon lumbar vertebrae showed that loss of normal support from the disc resulted in acute bone marrow depletion and trabecular bone necrosis [260]. This was followed by trabecular bone remodelling after intense osteogenesis [260]. These changes are consistent with those seen adjacent to narrowed discs in humans [260]. The authors concluded that the bony changes were the direct result of the failure of the disc to distribute the weight-bearing forces evenly over the vertebral body surface. This may also explain why disc degeneration is so strongly related to thoracic hyperkyphosis.

Another mechanism by which the disc may influence the shape of the vertebral bodies is described as ‘stress shielding’ [262]. It has been shown in a cadaveric model that disc narrowing leads to an alteration in the weight-bearing configuration of the thoraco-lumbar spine with weight being transferred to the neural arch (Figure 2.3). It is suggested that this abnormal decrease in weight-bearing forces may lead to loss of bone density in the anterior vertebral body with resultant bony failure in response to flexion [262]. In the mid-thoracic spine, the loss of disc height resulting from degenerative disc disease may cause stress shielding due to secondary loading through the costovertebral joints. These joints have been found to exhibit evidence of significant arthritic changes consistent with undue weight bearing in elderly cadavers [132].

Further evidence of the influence of the disc on the morphology of the vertebral body has been demonstrated in experiments which have found a relationship between the compressive stiffness and the thickness of subchondral bone and the proteoglycan content of the disc [264, 265]. The hydrostatic pressure exerted by the healthy, proteoglycan rich, disc apparently results in more bone being laid down; while bone next to degenerative, proteoglycan poor, discs is depleted [265].

While there are many causes which are understood to to lead to disc degeneration, there is a final common pathway which involves loss of nutrition to the disc [128, 266-270]. The many causes include mechanical factors such as compressive loading, shear stress and vibration as well as aging and genetic factors which result in biochemical changes, and toxicity [117, 271, 272]. The disc is the largest avascular structure in the human body [128, 273]. It is nourished by blood vessels situated at its periphery i.e. via marrow contact channels in the vertebral end-plate [128, 274, 275] and, to a lesser extent, from vascular networks. Some cells are up to 6-8 mm from the nearest blood supply in the outer annulus [266]. The bovine annulus has been shown to possess microtubules which run parallel to the collagen fibre bundles thereby favouring solute transmission from the end-plate [276]. The viability of the end-plate is therefore essential to the maintenance of adequate nutrition to the disc [274]. Disc degeneration is believed to be the result of chronic cell nutritional insufficiency which prevents the cells from renewing the extracellular matrix leading to a loss of proteoglycans and water-retaining capacity [277].

The effect of compression loading on the disc depends on whether it is sustained or dynamic. Sustained compressive loading results in reduced disc hydration [278] and a significant reduction in the transport of solutes via the end-plate [273, 276, 279, 280]. On the other hand, dynamic loading is believed to improve disc nutrition with increased oxygen concentration and reduced lactate accumulation [273]. Further, the detailed finite element model which predicted these effects calculated that after 200 cycles of dynamic compression at 0.1Hz, even discs with impermeable end-plates had up to 33% increased oxygen concentration in the nucleus, a 22% increase in the annulus fibrosus and a significant decrease in lactate concentration, especially in the annulus [273].

Discs adjacent to fused or immobilized segments have been reported to degenerate at an increased rate [281]. The underlying biochemical changes in immobilized discs have been partially investigated in a canine model which found decreased proteoglycan content and aggregating capacity in the discs of fused motion segments [282]. Thus, more sedentary lifestyles in which dynamic compression is less frequent may contribute to disc degeneration and age-related hyperkyphosis. The frequency with which people change position and the frequency required for ultimate disc health has not been investigated.

2.5.1.4. Muscle weakness

Hyperkyphosis and vertebral fracture have both been reported to be associated with loss of back extensor strength [10, 12]. As has been discussed previously, the erector spinae muscles are the main extensors of the back and so weakness of these muscles results in loss of extension of the spine [283]. During aging, humans have been reported to lose about one third of their skeletal muscle mass in a process called sarcopenia [284]. The potential mechanisms which result in the loss of muscular tissue and function are a focus of debate amongst muscle physiologists [285]. Current thinking points to disruption in muscle repair processes [286] and neurodegenerative causes [287]. Mature skeletal muscle is post-mitotic and so depends on precursor cells via growth factors to regenerate [286, 288]. Normal young muscle tissue responds to strain by initiating a mechano-growth factor response but in aging muscle this system becomes increasingly insensitive due to increasing connective tissue stiffness [286]. There is disagreement as to whether or not there is also a drop in the level of circulating hormones required for the expression of the genes needed to respond to physical activity [286, 288]. The net result is a situation where damaged muscle tissue is incompletely replaced [286, 288]. Aging also results in a gradual loss of motor units and a reduction in type II muscle fibres (fast twitch) [289].

There is evidence to suggest that some ‘orphaned’ type II fibres are adopted by type I (slow twitch) motor units and this may explain the variability in firing patterns which have been found in older muscle [285]. The erector spinae muscles in young subjects are composed of between 60% and 70% type I fibres which identifies them as primarily postural muscles [290]. Interestingly, the fibres in the thoracic spine are larger than those in the lumbar spine and, in women, the type I fibres are larger than the type II fibres which is not the case for males [290]. This may explain why women demonstrate better resistance to back muscle fatigue than men [291]. If type II fibres are selectively lost due to increasing age then it is conceivable that the erector spinae would be less able to generate the torque required to maintain an erect posture. This effect would be exaggerated in the presence of increasing curvature and resultant increased bending moments.

2.5.1.5. Camptocormia

Clinically, kyphotic deformity is often classified as either ‘fixed’ or ‘postural’[292, 293]. Fixed kyphoses are those that do not resolve when the person is put in a supine position. Those that do resolve when supine can be divided into two types: those in which the person is capable of active extension to reduce the kyphosis while erect (postural kyphosis), and those in which this is not possible (camptocormia). Camptocormia, or bent spine syndrome, is characterised by severe kyphosis of the thoracic and/or lumbar spine which disappears on lying supine [294] (Figure 2.17). It is characterized by progressive weakness of the paravertebral muscles in older people with a female predominance [295, 296]. Camptocormia occurs in disorders such as Parkinson’s disease where it is possibly associated with abdominal muscle dystonia [296, 297], as well as other movement and neuromuscular disorders (Table 2.4). In most cases camptocormia is associated with signs of focal myositis in the paravertebral muscles [298-301]. Biopsy of these muscles reveals increased fascicular fibrous tissue [298, 299] and selective loss of type II (fast twitch) muscle fibres [301]. It has been proposed that these pathological changes may be the result of excessive load placed upon the erector spinae by increased kyphotic posture [299] and/or excessive abdominal muscle activity [296]. It has also been suggested that the pathological findings found in camptocormia may also be present, and possibly causal, in people with age-related hyperkyphosis [295, 299]. The implication is that people with hyperkyphosis may develop pathological changes such as focal myositis in their extensor muscles as a result of mechanical overload induced by constantly having to resist the flexion moment induced by this position. Camptocormia is therefore included here amongst the possible age-related causes of hyperkyphosis.

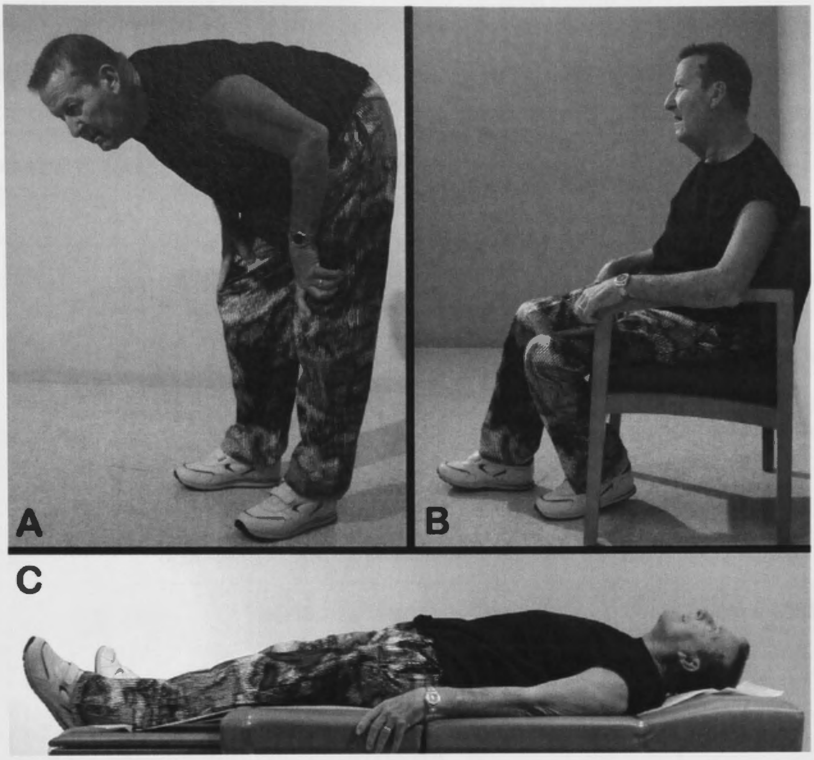

Figure 2.17 Person with severe camptocormia or bent spine syndrome.

A. Standing attempting to use upper limbs for support. B. Sitting reveals thoracic component. C. In supine the kyphosis disappears.

Note. From Azher, S.N. and J. Jankovic, *Camptocormia: pathogenesis, classification, and response to therapy.* Neurology, 2005. 65(3): p. 355-9 [296] with permission.

Table 2.4

Neurological causes of 'camptocormia"

Movement & CNS disorders	Neuromuscular disorders	
Gait disorders of aging	Myasthenia gravis	Metabolic myopathy
Parkinsonism	Myopathies	• Acid maltase deficiency
Dystonias	Dystrophy	• Carnitine deficiency
	• Limb-girdle muscular dystrophy 2B	Inflammatory myopathies
	• Facioscapulohumeral muscular dystrophy	• Focal myositis
	• Scapuloperoneal muscular dystrophy	• Inclusion body myositis
	• Welander distal myopathy*	Motor neuron disorders
	• Myotonic muscular dystrophy	Spinal muscular atrophy
	• Congenital muscular dystrophy	Benign focal amyotrophy of paraspinous muscles
	• Quadriceps myopathy*	Amyotrophic lateral sclerosis
	• Becker muscular dystrophy	

Note. Adapted from Mahjneh, I., et al., *Axial myopathy--an unrecognised entity.* Journal of Neurology, 2002. 249(6): p. 730-4.

2.5.1.6. Ligamentous degeneration

Ligaments are primarily involved in conferring stability to joints while not restricting functional movement. However, increasing age can make ligaments stiffer and restrict movement. Ligaments, like other connective tissues in the body, are primarily made up of collagen and elastin but the structure and content vary [145]. Elastin confers resilience and is found in tissues that have a special requirement for continuous extension and contraction or are continually exposed to deformation [145]. Among the spinal ligaments, the nuchal ligament has the highest elastin content (74.8%) [302] followed by the ligamentum flavum (46.7%) [303] and the posterior longitudinal ligament has the least (7.3%) [145]. Increasing age is associated with a loss of elastin and a relative increase in collagen content in connective tissues [304]. Evidence that ligaments may restrict extension of the thoracic spine is provided by a study in which the anterior longitudinal ligament between T3 and T7 was resected in cadavers. This resulted in an increase of 4° of movement at each motion segment [305]. As well as physical restriction, stiffening of the ligaments may compromise their role as sensory organs (2.4.3.11).

2.5.1.7. Diffuse idiopathic skeletal hyperostosis (DISH)

Diffuse Idiopathic skeletal hyperostosis (DISH) is a condition characterised by ossification of soft tissues, mainly entheses, ligaments and joint capsules, particularly the anterolateral aspects of the thoracic spine [306]. The condition causes increased thoracic stiffness and its prevalence increases with age, making DISH a relatively common entity in the elderly [306]. The prevalence in Europeans has been reported to be as high as 17% in people over 50 years [232] but it is much lower in Asians (2.9%) [307]. In Dutch men older than 80 years, the incidence has been reported to be 32.1% while it was just 16.9% in women [232]. Little is known about the pathogenesis of DISH but a robust body build in patients with DISH compared with non-DISH patients, expressed by either higher BMI or waist circumference, is a well-known feature [306]. Like ankylosing spondylosis, DISH can result in spinal stiffness and an inability to extend which can affect all regions of the spine [308]. DISH is included here because it can be a cause of hyperkyphosis and because of its high prevalence in older people.

2.5.1.8. Genetic predisposition

There is some direct and indirect evidence which suggests that some hyperkyphosis is heritable [19], but as yet the role of genetics is unclear. Older people who report a family history of 'dowager's hump' independent of osteoporosis and vertebral fractures have been reported to be significantly more likely to have more kyphotic curvature [19]. Klotho knockout mice which have been genetically manipulated to develop early senescence demonstrate a number of features commonly associated with aging [309, 310]. One of these is increased kyphosis which is curious given that they do not walk upright so gravity would not favour kyphosis. The Klotho knockout mice are also afflicted with osteoporosis consistent with it being the causal factor [309]. However, it is interesting to note that age-related kyphosis has been reported in several species of small tropical fish which do not develop osteoporosis, suggesting that soft tissues may play a significant role [311].

Twin studies have shown that disc degeneration, which is closely associated with hyperkyphosis, is more related to genetic factors than it is to environmental factors [117]. Furthermore, the risk of disc degeneration differs among races, the reported prevalence being of 43% among Caucasians, 31% in Africans, but only 8% in Asians [312].

The evidence therefore supports a significant genetic component of hyperkyphosis but further epidemiological research in humans is required before the true contribution of heritability can be determined.

2.5.2. Non age-related causes

Since the non age-related causes of kyphosis are not the focus of this thesis they are included in Table 2.5 which broadly classifies the causes of hyperkyphosis by pathology. One of the conditions, Scheuermann's Disease, will be discussed because it is relatively more prevalent than any of the other conditions and, although it is typically acquired in adolescence, the deformity persists throughout life.

Table 2.5

Pathophysiologic Classification of Kyphosis

1. Congenital	Defects of segmentation
	Defects of formation
	Fixed
2. Developmental	Scheuermann's kyphosis
	Developmental round back
	Spondylolisthesis
3. Inflammatory	Rheumatoid (ankylosing spondylitis)
	Infective
	Pyogenic
	Tuberculosis
4. Metabolic	Osteoporosis
	Osteomalacia
5. Post-traumatic	Fracture
6. Tumor	Metastatic
	Neurofibromatosis
	Other
7. Chondrodystrophic	Achondroplastic dwarf
	Mucopolysaccharidoses
	Spondylo-epiphyseal dysplasia
8. Iatrogenic	Post laminectomy
	Post irradiation
9. Neurological	Stroke
	Muscular Dystrophy
	Parkinson's Disease

Note: Based on Macagno and O'Brien (2006) [293].

2.5.2.1. Scheuermann's disease

Scheuermann's disease or kyphosis develops in childhood but it is relevant to this research because not only can the deformity persist throughout life, it can also be progressive [313]. Sorensen suggested that the diagnosis of Scheuermann's can be made when three adjacent vertebrae are wedged by at least 5° [314] but, because these criteria do not specifically differentiate Scheuermann's from other diagnoses, other criteria have been suggested including: kyphosis greater than 45°, disc space narrowing, irregular vertebral end-plates and Schmorl's nodes (herniation of disc material through the end-plate). The aetiology of Scheuermann's disease is not known, although there are many theories. It is generally agreed that mechanical factors play a significant role [313, 315]. Scheuermann himself noted that the majority of his patients were agricultural farm workers involved in repetitive heavy labour at an early age [316]. Adolescent butterfly swimmers have been reported to develop Scheuermann's [317], presumeably secondary to the excessive flexion loads placed upon the thoracic vertebrae from the latissimus dorsi and abdominal muscles. Schmorl suggested that the disc herniation and subsequent vertebral deformity in Scheuermann's disease is the result of focal weakness in the growth plate [318] and subsequent histological studies have supported this theory [319]. However, histological abnormalities do not prove a pre-existing condition because they may be the result of altered biomechanical conditions secondary to the kyphosis itself [313].

There is compelling evidence of heritability in Scheuermann's disease with the odds ratio for monozygotic twins both having Scheuermann's disease being 32.92 compared to 6.25 in dizygotic twins [320]. Of course, general morphology is also inherited and so the possibility of an increased vulnerability to mechanical load is not ruled out.

The incidence of Scheuermann's disease in the whole population has been reported to be 8% which is significant but too low to explain the incidence of age-related hyperkyphosis [19].

2.5.2.2. Effect of lifestyle

It is commonly believed that a sedentary lifestyle leads to increased kyphotic deformity but the evidence for this is not conclusive. There is some evidence to suggest that improved back extensor strength is related to decreased kyphotic curvature [10] and it would logically follow that more active women would have stronger back extensors and less kyphosis. However, a recent study of 189 women aged between 50 and 89 found that physical activity level was related to spinal range of movement but not to back extensor strength or degree of kyphosis [321]. This is supported by an earlier study which found that, although women who were active when younger seem to be active and stronger as older adults, this did not impact on the degree of kyphosis [322]. Another study of 449 post-menopausal women found that the wedge angle of the thoracic vertebrae was reduced in women who were more active, supporting the contention that physical activity may be effective in preventing age-related bone mineral loss, though specific data on the association between bone mineral density and physical activity levels were not reported [1]. In a cohort of 100 young men and women in their twenties, the prevalence of thoracic hyperkyphosis was reported to be 53.7% in women and 63% in men. However, there was no correlation between the level of physical activity and the degree of hyperkyphosis [323]. Further, in a study of young athletes, kyphosis was surprisingly found to be considerably increased in adolescents who trained regularly compared to their sedentary peers [210]. Thus, it would seem that although an active lifestyle may result in stronger and more physically active elders, the effect on the development, or not, of hyperkyphotic posture has not been established. There is, however, some evidence to suggest that changes in vertebral morphometry secondary to a reduction in BMD may be reduced with a more active lifestyle which also promotes better ranges of spinal mobility.

2.5.3. Summary

Thoracic hyperkyphosis in older people is commonly thought to be the result of osteoporotic fracture, but more recent evidence suggests that bony remodelling in response to the superincumbent forces imposed on the thoracic spine can also cause vertebral wedging. The most recent evidence suggests that hyperkyphosis is most strongly related to degenerative disc disease. Whereas static compressive forces lead to disc degeneration it is thought that dynamic compression increases disc nutrition. Muscle weakness has been associated with age-related kyphosis and, in some cases, neuromuscular changes in the erector spinae muscles may be a primary cause. Connective tissue changes are associated with aging with the prevalence of diffuse Idiopathic skeletal hyperostosis (DISH) increasing to 32% in males over 80. There is some evidence to suggest that there is a genetic component to hyperkyphosis which is independent of bone mineral density. The aetiology is therefore likely to be multifactorial. Whether an active lifestyle reduces the likelihood of developing hyperkyphosis is unclear but it does appear to be associated with better spinal range of movement.

2.6. Measurement of kyphosis

Thoracic kyphosis can be measured in a number of ways. Broadly there are two main types of measurement: radiological methods, which involve imaging of the bony skeleton; and non-radiological methods which involve taking measurements from the skin surface. A further distinction which can be made is between measurement methods that can capture dynamic information about the kyphotic curve during movement and those that are static. Although biplanar radiography [324], videofluoroscopy [325] and dynamic magnetic resonance imaging [326] are potentially all radiological techniques which could be used to capture dynamic information about thoracic kyphosis, they have not yet been used for this purpose. Therefore, the dynamic techniques that will be discussed in this section will all be non-radiological.

2.6.1. Reliability and validity

The assessment of a measurement tool involves a determination of its accuracy and precision. In the context of measurement devices for biological systems, the term accuracy is analogous to validity and precision is analogous to reliability. Assessment of the accuracy of a measurement device requires a standard with which it can be compared. This type of comparison validates the resolution of the instrument. Comparison of a device against another established technique or tool which measures the same thing is a test of concurrent validity.

Reliability refers to how repeatable the measurements are between sessions or between measurers (observers). If a measurement is intrinsically variable then it may be insensitive to the effect of an intervention or disease progression.

The intraclass correlation coefficient (ICC) is the most frequently used statistical measure of reliability [327]. Like all correlation coefficients, it reflects the relationship between measurements, but unlike the Pearson r, the ICC is also a measure of how well the measurements agree with each other [327]. The interpretation of the ICC may vary but in general values of 0.90–0.99=high reliability, 0.80–0.89=good reliability, 0.70–0.79=fair reliability, <0.69=poor reliability [328].

2.6.2. Radiological measurements of kyphosis

2.6.2.1. The Cobb angle

The Cobb angle or 'Cobb's angle' is the most common clinical method of measuring thoracic kyphosis and is therefore, perhaps inappropriately, considered the 'gold standard' [39, 329]. Cobb [330] describes how its use was first suggested to him by Dr Robert Lippman in 1935 but the originally named Lippman-Cobb method is commonly known as the Cobb angle today [25]. The technique was originally designed to measure the progression of the scoliotic curve in children [331], but it has since become the most widely accepted method of measuring the kyphotic and lordotic curves in the sagittal plane [25, 50, 331]. Hence the alternative label of the 'modified Cobb angle' when used for measurement of the sagittal curves.

The Cobb angle is measured from a lateral X-ray and represents the angle subtended by a line drawn over the superior end-plate of the most cranial vertebra pointing into the concavity and a line drawn under the inferior end-plate of the most caudal vertebra pointing into the concavity [25] (Figure 2.18). The original technique involved selecting the proximal and distal 'end vertebra' as those most tilted from the horizontal (the inflexion vertebrae) but practitioners and researchers vary in their interpretation of the technique, with anything from T1 to T4 being selected superiorly and T11 or T12 being selected inferiorly (Table 1.6.1). However, in clinical practice, the choice of end vertebrae is often determined by the visibility of the end-plates which, at the upper levels, are often obscured by the shoulder structures [21, 27].

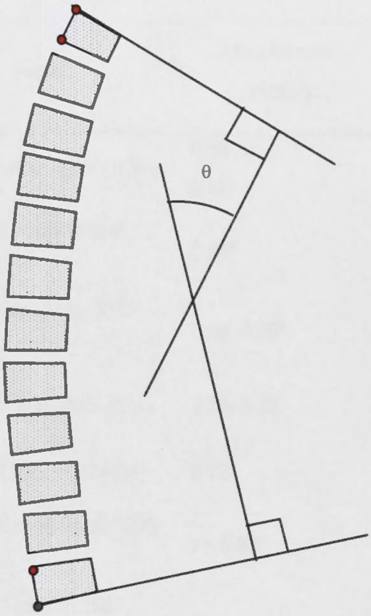

Figure 2.18 The Cobb Angle (θ).

The Cobb angle is favoured by clinicians because it is simple to acquire from a standard lateral X-ray which is ordered for diagnostic value and can be assessed for other pathological features such as fracture, osteophytes and schmorls nodes [240]. As a measurement standard, the value of the Cobb angle is hugely enhanced by the fact that it was the method used to formulate the normative data against which clinical judgements are made. Both the intra- and inter-observer reliability have been reported to be very high (Table 2.6).

Clinically, a change of 5 degrees in Cobb angle is considered to be 'significant' in terms of reflecting a real change in curvature but there seems to be little evidence for this figure [332].

Table 2.6

Papers reporting the reliability of static measurements of kyphosis

Measurement device	Paper	Intra-observer reliability	Inter-observer reliability	Concurrent Validity
Cobb Angle	Lundon, Li et al. 1998 [333]	0.99* 0.81†		
	Korovessis, Petsinis et al. 2001 [37]	0.98*	0.96	
	Briggs, Wrigley et al. 2007 [39]	0.98 -0.99*	0.83 – 0.99	
Cobbometer	Seel, Verrill et al. 2005 [334]	0.86- 0.98	0.95	
Flexicurve	Milne and Lauder 1974 [31]	0.78		
	Caine, McConnell et al. 1996 [335]	r = 0.93		
	Chow and Harrison 1987 [336]	0.98		
	Lundon, Li et al. 1998 [333]	0.87		
	Arnold, Beatty et al. 2000[337]	0.99	0.84	
	Hinman 2003[338]		0.94	
Debrunner's Kyphometer	Ohlen, Spangfort et al. 1989 [339]	r = 0.92 - 0.93	r =0.91 – 0.94	
	Lundon, Li et al. 1998 [333]	0.88		
	Korovessis, Petsinis et al. 2001 [37]	0.84	0.92	
Inclinometer	Mellin 1986 [340]	0.92 (day-to-day)		
	Lewis and Valentine 2010 [341]	0.97 (single session)		

Table 2.6 continued

Measurement device	Paper	Intra-observer reliability	Inter-observer reliability	Concurrent Validity
	Thompson and Eales 1994 [342]		0.83	
Spinal Mouse	Mannion, Knecht et al. 2004 [46]	0.73 - 0.88	0.73 - 0.88	
Photography	Leroux, Zabjek et al. 2000 [343]			0.94
	van Niekerk, Louw et al. 2008 [344]	0.96		0.93
	Dunk, Lalonde et al. 2005 [345]	0.64-0.73		
Kypho-lordometer	Ball, Cagle et al. 2009 [98]	r=0.82 -0.93		r = 0.58

Note. The correlations presented above are intraclass correlation co-efficients unless 'r' for Pearson's correlation co-efficient is specified. The cobb angle intra-observer correlations were achieved by either:-

* Repeated measurement of the same film; or

† Measurement of repeated X-rays of the same person

Despite the advantages listed above, the literature abounds with discussion concerning the various shortcomings and potential sources of error associated with the Cobb angle:-

1. Like all the X-ray based methods, it involves a radiation dose and is therefore not ideal for repeated measurement [333].
2. The position in which an X-ray is taken will affect the angle measured, and yet the standard position (erect standing with the arms supported at 90 degrees [25, 346]) is not always used. The kyphotic angle is significantly reduced in erect standing [44], and raising the arms can further decrease the kyphotic angle by up to 32% compared to having them hanging loosely by the side [347]. The literature clearly indicates however, that the standard position is not always used. Instead the positions used have included both 'standing erect' [35] and 'standing relaxed' [36, 348] with no mention of arm

position; and the arm position has been described as both by the side [32, 37] and above the shoulders [20, 331]. Use of the standard position ensures comparability between measurements and would move the scapula out of plane therefore promoting better visibility.

3. The Cobb technique relies on drawing a line on the X-ray along the end-plate. End-plates are often uneven, especially in the elderly and in the presence of end-plate disruption such as in Scheuermann's disease [349]. Therefore the choice of where to draw the line is highly subjective and may present a significant source of error [350]. Some authors have reported better accuracy with the use of digitized films and computer mediated measurement [35, 351]. Others have reported identical results for both but suggest that digitized measurement is more efficient [329].

4. Arguably, the largest potential source of absolute error when using the Cobb angle stems from end-plate tilt. Because the Cobb angle is derived from selected vertebral end-plates (see above), if these vertebrae are unusually tilted, the angle is exaggerated, and the angle of curvature is overestimated [27, 33, 35, 39, 50, 233].

5. As was discussed previously, the choice of end-vertebrae from which the Cobb angle is measured, is variable (Table 2.1). Logically, the Cobb angle is larger if more vertebrae are included in the curve being measured so, if the levels used are not standardised, they are not be comparable. This applies to both the comparison of one X-ray with a subsequent one as well as to the comparison of an angle with a 'normal value' data set such as that published by Fon et al. (1980) [20]. Studies which have examined the effects of pre-selecting the end-vertebrae when measuring the kyphotic curve have reported that it made no significant difference to the reliability [332, 352]. However in these studies, the X-rays were not serial films of the same patient, as would be encountered clinically or in an evaluation of an intervention, so differences in film quality or positioning would not have been an issue since they were assessing the same X-rays. In a study of scoliosis

however, the intra-observer variation was reduced from 4.9° to 3.8° by preselecting the 'end vertebrae' [353].

6. The accuracy of the equipment in terms of the quality of the protractor and the accuracy of the marker used have also been reported to significantly alter the measured angle [353, 354].

There is therefore, a mismatch between the reports of very high levels of reliability (Table 2.6) and the multiple sources of error listed above. These apparently conflicting ideas might be explained by the way the studies have been conducted. The vast majority of intra-observer reliability studies have assessed the ability of one observer to measure the Cobb angle on the same film twice, or two observers to measure the Cobb angle on the same film [37, 39, 333]. It is perhaps unsurprising that the correlations are so high. However, when Lundon et al. (1998) assessed the ability of observers to assess separate films of the same subject they found that the intra-class correlation coefficient decreased from 0.99 to 0.81 [333].

Perhaps an even more important issue for the clinician and the researcher is not whether a set of measurements correlate, but how well they agree (2.6.1). This is important because clinical judgments, such as whether surgery is indicated, are made on the basis of the extent of curve progression with five degrees being considered to be clinically significant. Carmen et al. (1990) used 'tolerance limits' for repeated measures of kyphosis and calculated that although the average difference between readings was 3.3°, an 11° change was necessary for 95% certainty of significant change between radiographs. Another group undertook a similar study and calculated that a 9.6° change was necessary for 95% certainty of significant change between radiographs [349]. Thus, the Cobb angle may not be as reliable in terms of precision as many clinicians would like to think, but when measured in terms of between measurement correlations, it has excellent reliability. This perceived lack of precision has lead researchers to investigate other methods of quantifying kyphosis from lateral X-rays.

2.6.2.2. The Oxford Cobbometer

The Oxford Cobbometer (Figure 2.19) is a specialized protractor which enables the Cobb angle to be read directly from an X-ray without the need for lines to be drawn [355]. The Cobbometer is commonly used in clinical practice because it is faster than drawing lines and avoids the errors caused by inaccurate equipment [334]. The Cobbometer has been reported to be more reliable than the traditional Cobb angle measurement technique (Table 2.6), but the study suggesting this was done on local measurement of fracture kyphosis rather than the whole thoracic curve [334].

Figure 2.19 The Oxford Cobbometer

2.6.2.3. Harrison posterior tangent and the centroid techniques

The Harrison Posterior Tangent [26] and the Centroid techniques also measure the kyphotic angle from lateral X-ray [26, 39]. They are both designed to avoid errors associated with excessive end-plate tilt by using other anatomical features of the vertebra to construct the lines from which the angle is derived.

The posterior tangent technique involves constructing two lines from the two posterior corners of the top and bottom vertebrae to be measured (Figure 2.20). The angle is that which subtends these lines. It is difficult to determine the origins of this technique but the first report in the peer reviewed literature is in 1998 when it was used to evaluate lumbar spine lordosis [356].

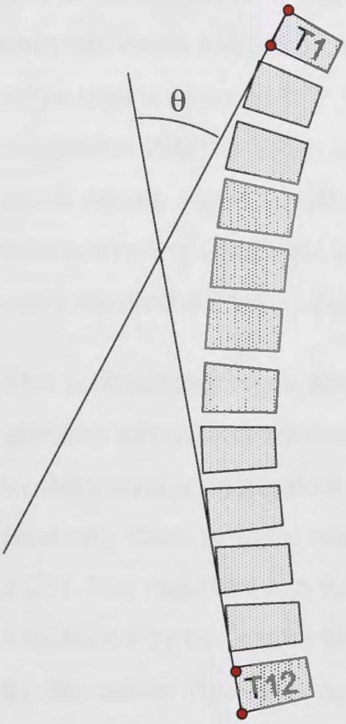

Figure 2.20 Harrisons posterior tangent technique

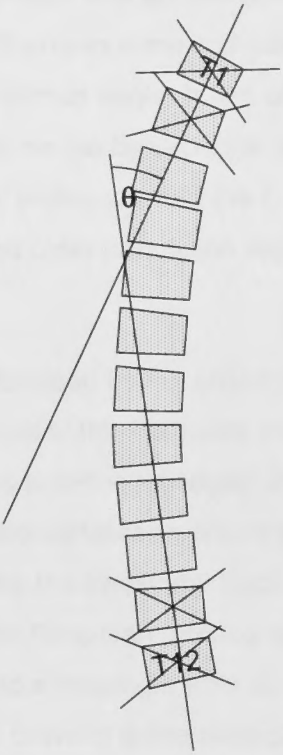

Figure 2.21 The centroid technique

The centroid technique is derived from Fergusons technique for measuring scoliotic curves [25]. It involves drawing diagonal lines between the corners of each of the two vertebrae at the top of the curve, and the two at the bottom of the curve. Where the lines intersect is the centroid. Construction lines are then drawn through the centroids at the top and bottom of the curve and the angle is derived from where they meet as per the Cobb and posterior tangent techniques (Figure 2.21).

Two studies have compared the posterior tangent and/or the centroid method with the 'traditional' Cobb method using different populations [26, 39]. In young subjects both the intra and inter-observer reliability was excellent for all three methods (ICC>0.96; absolute differences between measuremens < 2.96º) [26]. In a cohort of older osteoporotic women the Cobb angle and the centroid angle between T1-T12 were also highly correlated (r=0.84) [39]. As in the previous study, the centroid and Cobb angles for T1 to T12 were very similar with an average of just 1° between them. However, when the T4 to T9 angles were compared, the Cobb angle was a mean of 6.3° larger than the centroid angle. It has already been suggested that the Cobb angle is highly influenced by vertebral deformity and these results seem to reflect this flaw in the technique with the Cobb angle overestimating the angle when applied to an older population within a region of more marked deformity [39].

The centroid technique however is also influenced by the shape of the vertebra, a problem which was addressed in descriptions of the Ferguson method [25], but not by the above investigators. If the vertebra is anteriorly wedged, the centroid will be relatively more anterior than it would be if the vertebrae were rectangular (Figure 2.21). The resultant line would therefore, like the traditional Cobb method, be influenced by the shape of the vertebra. The Ferguson method accounted for that by stipulating that the shape be converted to a rectangle prior to determining its centre [25]. An alternative method involves drawing a line through the centre of the upper and lower end-plates rather than using diagonals to determine the centre of the 'end-vertebrae' (Goh 2000). This technique preserves the central location in the presence of deformity and derives the line from one vertebra only. When compared with the Cobb angle, this 'alternative Cobb' angle, was highly correlated (r=0.99) with a mean difference of just 1.4°± 4.1°. However, once again, where the 'end-vertebrae' were severely deformed, the individual differences were large which illustrates very clearly how much the Cobb angle is influenced by end-plate tilt in the presence of vertebral deformity [50].

2.6.2.4. Geometrical characterisation of the kyphotic curve

The practical advantage of describing the thoracic curve geometrically is that it does not require the end-vertebra to be identical to be able to make comparisons [55]. The disadvantages are that it potentially takes more time, advanced imaging technology and, ideally, a set of normative values against which to compare the data. To date, geometrical modelling has not made many inroads into the clinical arena, but perhaps the advent of digital radiography and more understanding of modelling technology will alter this situation.

Expressing the thoracic curve as a radius of curvature is the simplest geometrical modelling technique [27, 35, 50]. The radius of curvature has been reported to correlate highly with the Cobb angle (r=0.9) but this correlation decreases as kyphosis decreases [50]. Interestingly the radius of curvature has been found to be better than the Cobb angle at predicting neurological deficit due to kyphotic deformity [357]. However, a number of investigators have rightly pointed out that the kyphotic curve is not simply an arc of a circle, in fact it more closely represents a portion of an elipse [55]. Thus measurement methods such as the Cobb angle and its correlates, as well as the radius of curvature, describe the relationship between the end vertebrae rather than the intervening curve [33].

It has been proposed that expressing the curve as a ratio of the height and depth (the kyphotic index) is more descriptive of the curve [33]. This technique requires that T1 defines the top of the curve which arguably limits its advantage as a radiological measure since T1 is difficult to image. However, the kyphotic index is used in combination with the flexicurve, and this application is discussed later (1.6.3.1).

Expressing the kyphotic curve as a polynomial equation has yielded some interesting findings, such as the discovery of an age-related caudal shift in the thoracolumbar inflexion point [35]. However polynomial models have been described as having complicated coefficient parameters which are difficult to use in a clinical context [55]. This certainly has seemed to be the case but a recent study has utilised polynomials in a much more clinically interesting way [39]. Briggs et al. (2007) fitted cubic polynomials to the centroid profile of individual participants and, in a matter of minutes were able to derive the gradient of the curve at each spinal level [252]. The increase in the availability of digital imaging technology and analysis software will undoubtedly bring this type of technique into both the research environment and the clinic.

Harrison et al. (2002) examined whether the thoracic curve could be successfully modelled as an elipse [55]. They determined that the elipse best fitted the region between T2 and T11 with the curve flattening above and below these points. The lower segments were shown to be flatter while the upper segments were more curved. The minor to major axis ratio for the average curve was either 0.6 or 0.72 depending on whether the minor axis was fixed at T12 or allowed to vary. Unlike a circle, an elipse has two axes which are theoretically infinitely variable. Therefore, although an interesting idea, eliptical modelling has too many parameters to make it useful as a measurement which reflects the degree of change in kyphotic angle.

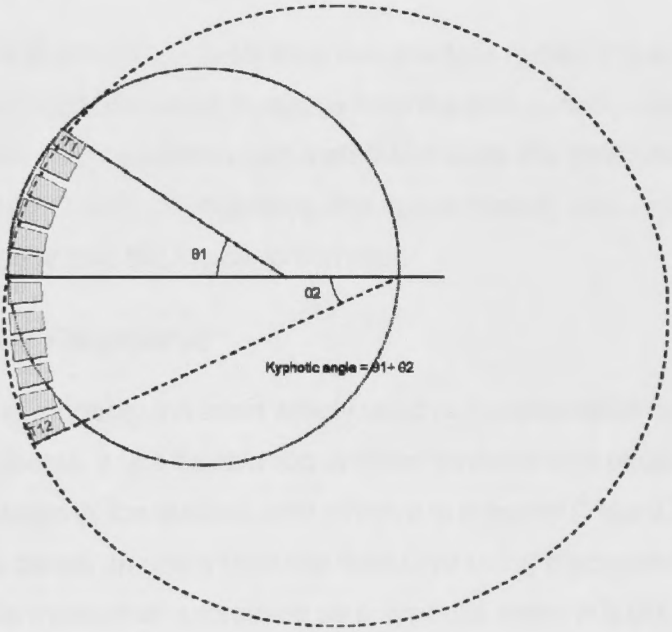

Figure 2.22 The tangent circles technique

The tangent circles technique is described as a more clinically applicable method than elliptical modelling of the spine [358]. It is based on previous work which used a computer programme to model the kyphosis as the arc of a single circle [359] and attempts to overcome the fact that the radius of curvature in the upper thoracic spine is smaller than it is at the bottom (flatter) part of the spine by dividing the thoracic curve into two regions defined by the apex (Figure 2.22). The kyphotic angle is calculated as the sum of the angles subtended by the arcs of two circles defining the upper and lower curve, tangent at the levels of the apex. This technique was reported to have excellent intra and inter-observer reliability, and it also correlated well with the Cobb angle (r=0.93) but the mean tangent circle angle was significantly smaller than the Cobb angle (4.3°) [358]. The use of two circles to define the curve introduces an additional degree of freedom much like the two axes of the elliptical technique. It is a complicated method and its advantage over the Cobb angle is not entirely clear although it does not require identification of the upper end-plate.

2.6.3. Non-radiological static measures

Radiological measurement is expensive and involves radiation exposure so a number of other methods which measure from the skin surface have been designed. These static measurement methods include the flexicurve, Debrunner's kyphometer, inclinometry, photography, the spinal mouse, video rasterography, spinal pantography and the kypho-lordometer.

2.6.3.1. The Flexicurve

The flexicurve is probably the most widely used non-radiological measurement tool for thoracic kyphosis. It is a flexible rod of metal covered with plastic, which assumes the shape of the surface onto which it is pressed (Figure 2.23). Although it is possible to derive an angle from the flexicurve using trigonometry [360], the measurement is most often expressed as a kyphotic index (KI) [31, 336, 361](Figure 2.23). The advantages of the flexicurve are that it is reliable (Table 2.6) and that it is very simple, inexpensive and non-invasive [44, 335, 336, 342, 362]. Although the repeatability statistics for the flexicurve are not as uniformly high as those reported for the Cobb angle on single X-rays, they are higher than those reported for successive X-rays which is the measurement with which they should be compared.

KI values above 10 -11 [362] or 13 [336] have been reported to be indicative of hyperkyphosis but no objective validation studies have been used to support these thresholds.

The primary disadvantage of the flexicurve is that it can unbend during the process of transferring it from the subject's back to paper. It has been suggested that accuracy could be improved by mounting the device on an adjustable stadiometer [335] but this would vastly reduce the utility of the device in terms of cost and convenience.

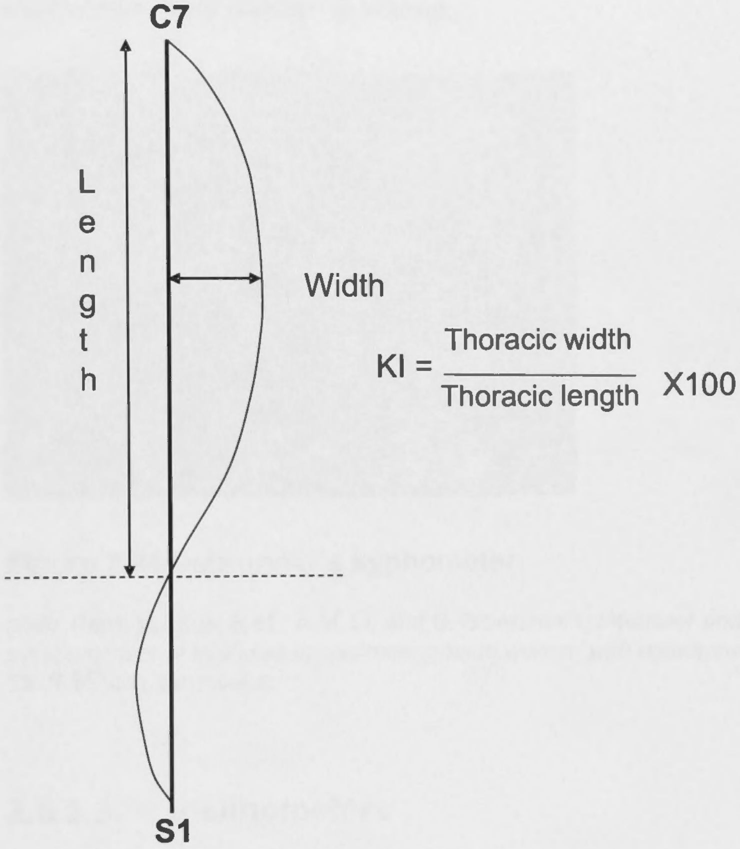

Figure 2.23 The flexicurve method of deriving the kyphotic angle

2.6.3.2. Debrunners kyphometer

Debrunner's kyphometer has also been used to measure kyphosis in a number of studies [9, 37, 329, 333, 339, 363-365]. It is essentially a large protractor with two double arms at the end of which are blocks large enough to span two spinous processes [339] (Figure 2.24). It is capable of measuring the kyphotic angle very quickly and directly which makes it a valuable clinical and research tool. The kyphometer is reliable (Table 2.6) and, with the use of a correction algorithm, can potentially predict the Cobb angle to within 2.84 ± 0.85° [37].

There appear to be few disadvantages associated with the kyphometer except that it is relatively, much more expensive than the flexicurve and, in the author's experience, very difficult to source.

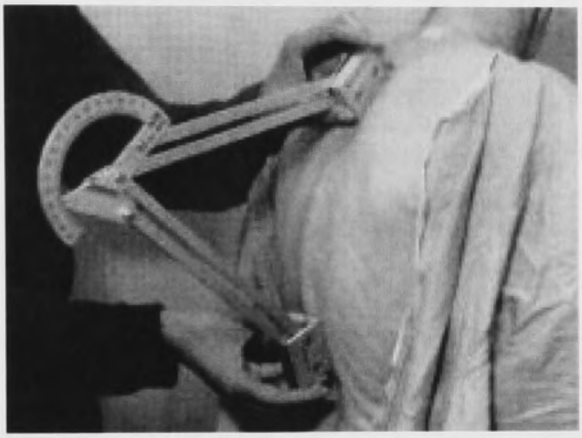

Figure 2.24 Debrunner's kyphometer.

Note. From Lundon, K.M., A.M. Li, and S. Bibershtein, *Interrater and intrarater reliability in the measurement of kyphosis in postmenopausal women with osteoporosis.* Spine, 1998. 23(18): p. 1978-85 with permission.

2.6.3.3. Inclinometers

Inclinometers are simple pendulum goniometers consisting of a protractor with a gravity dependent pointer at their centre (Figure 2.25). By positioning the feet of the inclinometer either side of the end-vertebrae at the top and the bottom of the curve, the angles which are tangent to the surfaces can be measured and subtracted from each other to yield the angle of curvature [3, 7] (Figure 2.25).

Reliability studies have shown variable results for inclinometers (Table 2.6) The original reliability study reported that, for all nine subjects in the study, the average measurement variation was 14 degrees, or 11.4 % of their average total range of spinal movement [7]. This variation was halved when the skin markings were not removed between measurements and the measurements were repeated on the same day. More recent reliability studies have reported much better reliability levels (Table 2.6).

More recent versions of the inclinometer include the plurimeter and the electronic dual inclinometer. The plurimeter is a liquid pendulum inclinometer with a rotating protractor face. The electronic dual inclinometer has two linked sensor blocks containing solid state accelerometers which, when simultaneously placed on the top and bottom of the curve, return the angular data digitally (Dualer IQ, JTech Medical, Utah) (Figure 2.26). To date there is no reliability data for the plurimeter or the dual inclinometer but the dual inclinometer has been used to evaluate kyphotic angle [366].

The advantage of the inclinometer is that it is simple and relatively inexpensive, although that cannot be said for the electronic device. Although the inclinometric method has been used in a number of thoracic spine studies, it is not as widely reported as the flexicurve.

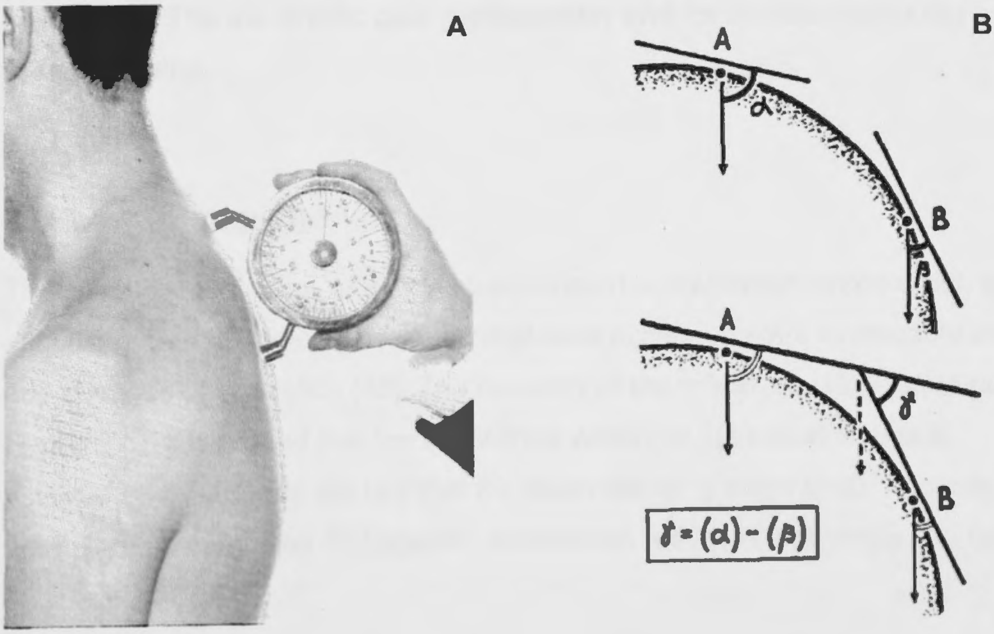

Figure 2.25 The inclinometer

A. The device used by Loebl; B.The method for calculating inclinometer values

Note. From Loebl, W.Y., *Measurement of spinal posture and range of spinal movement.* Ann Phys Med, 1967. 9(3): p. 103-10 with permission.

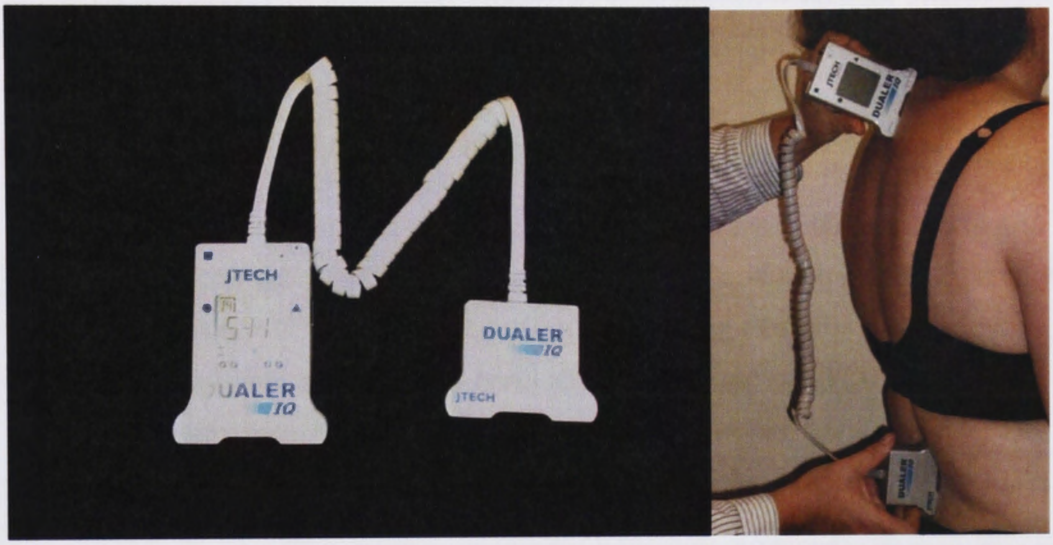

Figure 2.26 The electronic dual inclinometer and its application to the thoracic spine.

2.6.3.4. Spinal mouse

The spinal mouse (Idiag, Voletswil, Switzerland) is a wheeled device which is effectively an electronic inclinometer that uses accelerometers to measure distance and changes of inclination [46]. The reliability of the spinal mouse is fair to good (Table 2.6). It is argued that the concurrent validity of the spinal mouse is established by virtue of the fact that the mean standing angle of 45° accords with a number of other studies, but specific comparison with the Cobb angle has not been performed [46].

To date, the spinal mouse has been used to measure kyphosis in two studies [283, 367]. It has the advantage of being easy to use and able to measure global and segmental angles in different positions quickly, but has the disadvantage of being expensive and less reliable than other methods.

2.6.3.5. Photography

Photography has been used to study posture since 1941 [368]. Since this time, although single camera photography is still used, more sophisticated multiple camera and video capture systems have evolved [369]. The use of external reference points such as plumb-lines have been shown to have poor repeatability with skin-markers proving to be more reliable [344, 345].

Measurements taken from single camera views are always potentially subject to parallax and perspective error [370]. However, when measuring static postures, if the camera position is standardised and positioned at the centre of the segment being measured, these errors have been shown to be negligible [371, 372]. Photography has been shown to correlate well with the Cobb angle but the intra-observer reliability varies from fair to excellent (Table 2.6).

Photography has been used by a number of groups to assess kyphosis [345, 368, 373, 374]. Photography is non-invasive and relatively inexpensive but the camera position and reflective skin marker position must be precisely reproduced on each measurement occasion. Photography has the advantage of recording tangible visual data from which both quantitative and qualitative assessments can be made.

2.6.3.6. Video raster-stereography

Video raster-stereography is a method of back surface measurement which uses automatic back surface reconstruction and shape analysis [375]. [375]. Raster-stereography has been not been widely used [210, 376]. The reliability has not been specifically reported but differences between it and the Cobb angle of up to 14° have been reported [377]. The advantage of this method is that it generates three-dimensional information without exposing the subject to radiation. A major disadvantage is that it is expensive and not widely available.

2.6.3.7. The kypholordometer

This simple device consists of movable horizontal rods which are slotted through a vertical pole or board and arranged equidistantly one above each other (Figure 2.27). The subject stands by the pole and the rod ends are located against the contour of the spine thereby reproducing the curve. The curve is then transferred to a piece of paper [378, 379], or graphed according to the lengths of the rods from the pole [98]. Although angles can be derived from the resultant curve the area under the curve has also been used to quantify the degree of kyphosis [98]. The reliability of this method is good to excellent (Table 2.6) but when compared with radiological measures for the lumbar spine the agreement was poor with significant dispersion and a systematic error of 5.4° [378]. The kypholordometer has not been widely used but is included here because it has been used in a recent intervention study [98].

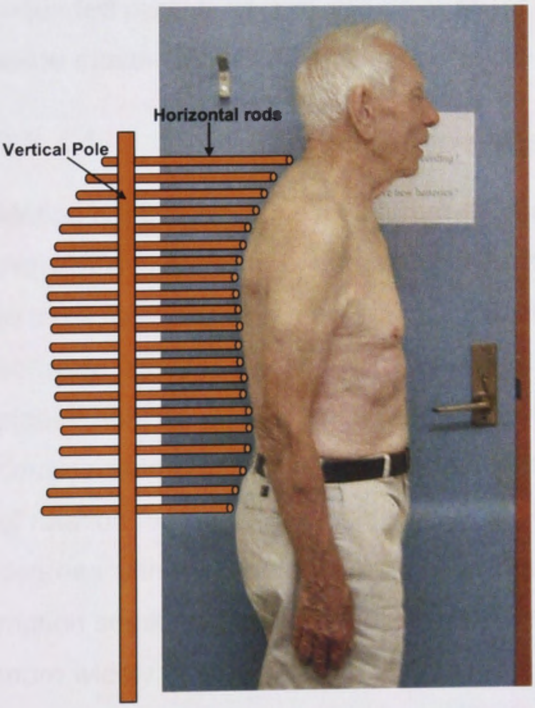

Figure 2.27 Diagramatic representation of a 'kypholordometer'

2.6.4. Non-radiological dynamic measures

The dynamic measurement systems which will be discussed in this section include optoelectronic systems, magnetic tracking systems, inertial systems, direct measurement and electrogoniometry. These systems can provide continuous angular data in dynamic situations, identifying functional problems in a way that is not possible with static systems [380]. However, some of these devices are limited by the fact that they can only be used in the laboratory or clinical environment, with some requring large dedicated spaces while providing only short term dynamic measurements [381]. Others, such as the flexible electrogoniometer and inertial systems, have the potential to record information outside the laboratory for extended periods of time and so open up new possibilities for evaluating how the spine moves in normal environments.

2.6.4.1. Opto-electronic devices

Motion capture systems measure movement in three dimensions. They emerged in the 1980s in the form of opto-electronic devices which use multiple video cameras to track reflective skin markers as subjects move or perform particular tasks. The software converts the co-ordinates of the markers into angles of rotation in three planes, making this type of system capable of describing movement in considerable detail. This technology is reported to be capable of producing angles of rotation for the lumbar spine which have maximum errors about any axis of +/- 2 degrees with an absolute error of less than 1° [382]. Although 'visible light' video motion sensor systems are still used, infrared video motion sensing has become more widely used to capture motion [383]. It has several advantages over visible light video systems including the ability to track the sensors without interference from other light producing sources, since they do not detect visible light [384]. The accuracy of infrared video motion sensing has been shown to be very high as long as the distance between the cameras and the markers used during calibration is maintained throughout the measurement [383]. Apart from the problem of camera distance, other major limitations of optoelectronic systems are that they are limited to the laboratory, require large dedicated spaces, and are relatively complex to set up and interpret [380, 381, 385].

2.6.4.2. Electromagnetic systems

Electro-magnetic systems are also three dimensional measurement devices which have been used extensively in human posture and movement analysis [82, 386-394]. These systems tracks movement by calculating the position and orientation of sensors relative to a source (mounted nearby or on the body) which emit a low frequency electromagnetic field [385]. The advantage of the electromagnetic systems is that they are easier to use than the opto-electronic systems and are considerably less expensive [385]. They are also smaller and relatively more portable [381]. The error measured for lumbar spine movements is reportedly less than 0.2 degrees however, like other surface measurement devices, it did overestimate lumbar spine motion compared to measurements from biplanar X-ray by about 6° in the sagittal plane [385]. Maximal measurement error between repeated measurements of the thoracic spine using an electromagnetic tracking system has been reported to be up to 3° [49]. A major limitation of the electromagnetic system is that it has a very restricted operational zone because the accuracy of the signal becomes less accurate with increased distance making the measurement of activities such as gait problematic [381]. Electromagnetic systems also have the disadvantage of generating significant errors (-5.4° +/- 3.4°) in angular data in ferromagnetic environments such as within rowing ergometers [395].

2.6.4.3. Inertial measurement

Inertial measurement units are integrated electronic devices that contain accelerometers, magnetometers and gyroscopes [396]. A study of a system which used tri-axial accelometers and gyroscopes reported minimal intrinsic error (<1.5°) when tested on a calibration rig [381]. When compared with an optoelectronic system, the Pearson correlation coefficient for the T1 to T12 angle was reported to be between 0.78 and 0.98 depending on the activity measured. The mean absolute difference in measured angle between the two systems was less than 3.1° [381].

However, independent testing of five different inertial measurement units found that the maximum absolute static orientation error was 5.2 degrees and it was suggested that larger scale global motions may be subject to errors of up to 9.8 degrees [396]. It is, however, further suggested that revising the calibration methods markedly reduces the error [396]. Wearable motion capture systems based on inertial sensor technology have been proposed as alternatives to optical motion capture because they have the advantage of being able to capture information outside of the laboratory [397]. However, although this technology has tremendous promise, there are a number of technical issues which have yet to be resolved in order to ensure adequate accuracy [396].

2.6.4.4. Hybrid systems

Hybrid systems which utilize infrared, inertial and accelerometer technology have been recently introduced [398]. It is claimed that they are less complex and less expensive because they utilize off-the-shelf components [398]. This technology has not, as yet, been applied to the thoracic spine.

2.6.4.5. Direct measurement from the spinous processes

This invasive technique involves putting Steinman pins [176] or Kirschner wires [399] into the spinous processes in order to directly measure spinal rotation in three dimensions. Sagittal movement of the thoracic spine has not been evaluated with this method. It is difficult to imagine how the authors of these studies secured ethical approval, but reference to these studies are included for the interest of the reader.

2.6.4.6. Electrogoniometry

Electrogoniometry or potentiometric goniometry uses potentiometers to convert joint rotation angles into an electronic signal which is then converted into continuous angular data [380, 381, 400]. The electrogoniometer was first described in 1959 [401] and various versions of the device have since been developed and/or used to measure cervical, thoracic and lumbar spine movement [402-407]. Early designs were accurate but bulky and uncomfortable to wear [380]. More modern versions are lighter and can be simply applied to the skin with double sided tape, but only the flexible electrogoniometer (below) can be used in the domestic and community environment during normal daily activities due to its small size and low profile [380, 408]. However, by using a 6 degree-of-freedom spatial linkage, the larger devices are capable of three dimensional measurements which the flexible electrogoniometer is not [403, 405].

2.6.4.7. The flexible electrogoniometer

The Biometrics flexible electrogoniometer (FEG) (Biometrics, Cwmfelinfach, Gwent, UK) is a lightweight device which can record angular motion outside the laboratory. It was developed in 1989 and consists of two lightweight plastic end-blocks at either end of a separating coil containing a narrow strip of steel foil on which two strain gauges are mounted at 90º to each other [380] (Figure 2.28). This configuration allows the measurement of the angular displacement of one endblock relative to the other in two planes which are at 90° to one another e.g. flexion/extension and side flexion of the spine. The flexible design of the FEG means that it does not have a centre of rotation and so it can measure rotation about polycentric joints without the need for complicated mechanical linkages [408]. Because the FEG works on the principle of summated strains, the angle measured is a reflection of the relative position of the end-blocks regardless of what is happening to the coil in between, although buckling of the coil is not ideal [408]. For this reason one of the end-blocks has a sliding function which permits the distance between the two end-blocks to change during joint rotations by telescoping in and out without altering the relationship between the endblock and the strain gauges [408]. This prevents damage to the strain gauges from over stretching or buckling. The data can be recorded on a datalog unit which stores the electrical signals digitally at preselected frequencies [409]. The datalog unit weighs just 156 grams and when worn by the subject, can be taken out of the laboratory into the community. The datalog is capable of storing up to 10 hours of continuous angular displacement data which can be downloaded into a computer for subsequent analysis by specially designed software (Biometrics LTD, Datalog Management & Analysis SW475-1111, version 7.5).

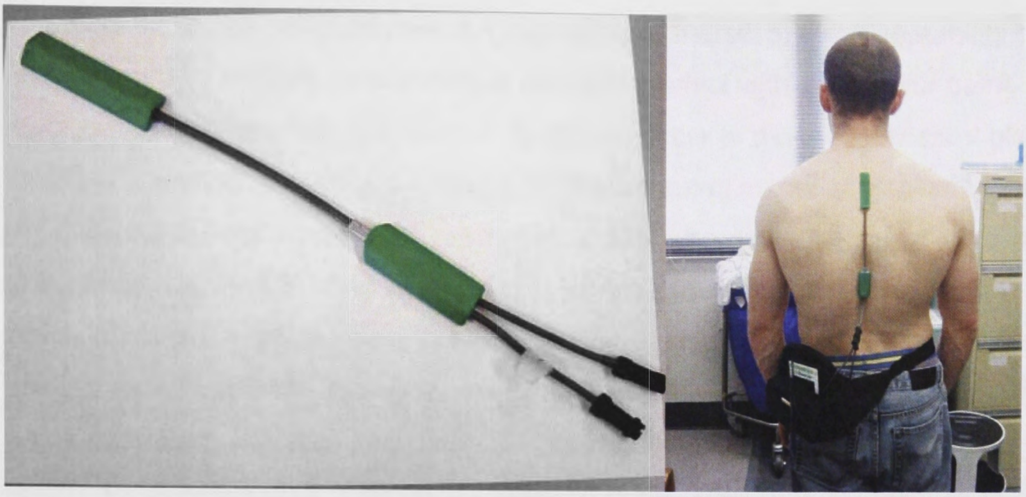

Figure 2.28 The flexible electrogoniometer and its application to the thoracic spine

Apart from the major advantage of being able to quantify angular position and motion outside of the laboratory, the Biometrics software, which processes the data from the FEG, is also capable of measuring the frequency at which the angle of the back changes in both the sagittal and coronal planes [409]. This is useful in view of the fact that disc nutrition has been reported to be enhanced by movement, potentially making the quantification of movement frequency an important outcome in any treatment intervention.

Both the accuracy and the concurrent validity of the FEG have been examined. When compared with a precision jig the resolution of the FEG has been shown to be accurate to 1°[410]. When compared with the Cobb angle the FEG is reported to be well correlated but only Peasons r is reported (r=0.89) [411]. Comparison of knee rotations during gait with an opto-electonic system revealed mean differences in measured knee angles of between just 1.2° and 2.1° [408]. Finally, a lumbar spine study showed similarly small mean angular differences but absolute angular differences of 3.9° and 5.9° between the FEG and the flexicurve and inclinometer respectively [412].

The FEG exhibits a small degree of hysteresis and therefore the repeatability of the FEG in terms of multiple movements is not quite perfect with ±1°of error being reported [408]. 'Crosstalk' errors of up to ±3°can occur in the measurement plane if the FEG is moved through more than ± 60° from neutral in one of the other planes [413]. These results agree with Rowe et al. (2001) who detected 'crosstalk' errors of between 1.8° and 2°. However, since ± 60° is relatively extreme for a movement which is not in the measurement plane, it was suggested that the error detected is unlikely to influence the measurement of range during functional activities [408]. In a separate study Shiratsu and Coury (2003) tested a selection of flexible electrogoniometers on a triplanar precision jig [410]. They detected similar levels of crosstalk error and also recommended that individual FEGs should be assessed for accuracy prior to use, especially where comparisons are being made between sensors [410].

The intra-observer reliability of the FEG has been assessed for measurements of both the thoracic and the lumbar spine [412]. In a study of lumbar spine movement, flexion angle was recorded by the FEG on two separate occasions requiring reattachment. The Pearsons r of the first compared to the second occasion was 0.78 with an absolute error was 5.73°. When compared with the flexicurve and the inclinometer the FEG demonstrated more error and lower correlation coefficients, but the methods were reported to be statistically indistinguishable [412]. Only one study has examined the reliability of FEG measurement in the thoracic spine [411]. In this study the intra-observer (test-retest) measurements of the sagittal thoracic angle between T3 to T10 was reported to have an ICC of 0.98 [411]. However, the device was not removed between measurements and so was arguably not really a test of repeatability.

The FEG is a skin-based measurement and therefore can only give an indication of the skeletal spinal curvature. Previous studies have reported a discrepancy between other skin-based measurements of kyphosis and radiological measures [37, 333, 414]. Furthermore, although the FEG has been used to measure various joint angles during functional activities [408, 412, 415-417], and one group has used it to measure the thoracic spine [411, 418, 419], a thorough validation of the

FEG as applied to the thoracic spine has not yet been undertaken. Indeed, the question of what vertebral segments are actively being measured during spinal applications of the FEG has not yet been addressed. This is important because the end-blocks on either side of the strain gauges are long enough to span two, or even three, vertebrae.

2.6.5. Summary

The degree of kyphosis can be reported as an angle, an index or an equation. Each has relevance, but measurements which return an angle are more easily interpreted, both when comparing outcomes of interventions, and with 'normal' data. The radiographic methods are most commonly used in clinical practice, though skin-based techniques are of increasing interest to clinicians and researchers because they do not result in exposure to radiation. The Cobb angle, for all its shortcomings, is the most widely used method and is considered to be the 'gold standard' [19], although the centroid method is arguably a better alternative [26, 39]. Skin-based measures of the thoracic spine are typically about 5° different to the Cobb angle [343] but of course this figure varies depending on the extent of the thoracic spine measured.

Static measures of kyphosis are limited because they reflect best behaviour rather than true functional ranges.

There are a number of motion capture systems which have been used to measure spinal movement. Of these the flexible electrogoniometer is of most interest because it has been shown to exhibit minimal error and is capable of measuring range of movement in unconstrained conditions outside the laboratory [408]. The FEG however, has yet to be thoroughly validated for use in the thoracic spine.

2.7. Measurement of muscle function

2.7.1. Myometry

Muscle strength can be measured manually, in which case a 6 point (0-5) ordinal scale is used [420]. If a more accurate quantification is required it can be measured electronically by myometry [421]. Accurate strength measurement is relevant to the investigation of kyphosis because of the reported relationship between back extensor strength and kyphosis [10-12] (2.5.1.4). Myometry can be performed with the myometer held in the operator's hands or, if the muscles to be measured are too strong for the operator to resist adequately, it can be mounted on a wall or within specialised apparatus [422]. Hand held myometry has been shown to have poor reliability when used to measure the back extensors [8]. In most studies of back extensor strength in relation to kyphosis, the subjects have been measured in prone lying using a strain gauge dynamometer as a myometer [10, 90, 283, 423] (Figure 2.29). This method is reported to be safe and reliable with a coefficient of variation between measurements of just 2.33% [423]. However, the prone position required for this measurement technique, has been reported to preclude the measurement of the elderly or very kyphosed because they cannot lie prone [283]. Others have used isokinetic training devices to capture isometric torque measurements with the subject positioned in a sitting position [321]. Test-retest reliability, expressed as an intraclass correlation coefficient, was reported to be good at 0.76 [424] and 0.84 [8]. Seated isokinetic devices of this type are, however, designed to facilitate extension of the lumbar spine but they do not specifically isolate extension of the thoracic spine. Therefore, a method of strength measurement which is designed to specifically target thoracic extension and which could be undertaken in a sitting position rather than prone lying would potentially be more useful. Mika et al (2005) measured isometric back extensor strength in a sitting position with the transducer pad positioned at the level of the superior border of the scapulae so as to specifically target the thoracic spine, however they did not publish any reliability data [11]. Hand-held myometry is not a useful way of measuring the erector spinae because they are too strong.

Seated, wall mounted myometry with the tranducer positioned at the level of the scapulae as described by Mika et al (2005) is potentially a more effective way of measuring back extensor strength in the thoracic spine, but this method has not yet been validated.

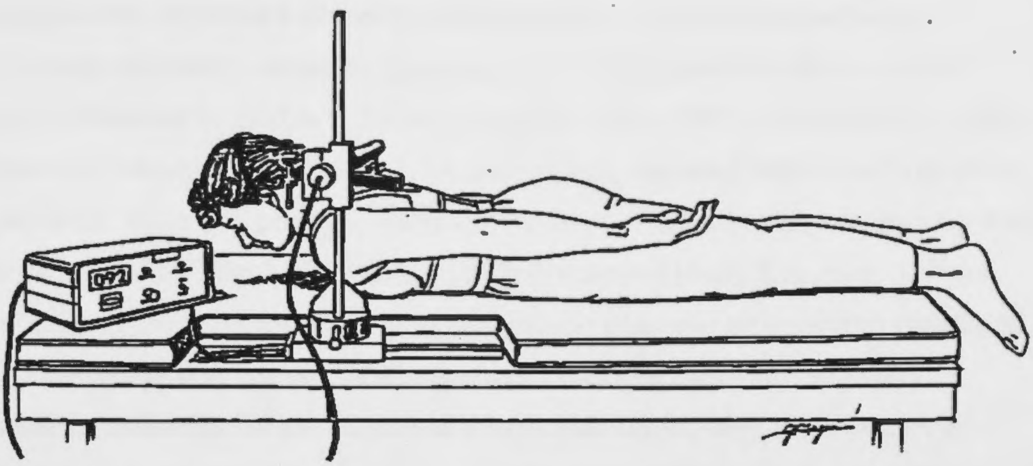

Figure 2.29 Diagram showing prone back extension strength measurement using the BID-2000.

Note. From Limburg, P.J., et al., A useful technique for measurement of back strength in *osteoporotic and elderly patients.* Mayo Clin Proc, 1991. **66**(1): p. 39-44 with permission.

2.7.2. Electromyography

Surface electromyography (sEMG) has been used extensively to measure muscular activity in the thoracic and lumbar erector spinae muscles [218, 219, 366, 425-435]. sEMG has advantages over needle electromyography (nEMG) in that it is non-invasive, painless and capable of measuring electrical activity from whole muscles rather than from single motor units [436]. This makes sEMG an ideal tool for measuring muscle activity during functional activities during which needles can become dislodged or cause pain [437], potentially inhibiting normal activation [438]. However, sEMG electrodes measure the activity of the muscle lying directly beneath them which constrains the use of sEMG to sites where there is no superficial muscle present to generate cross-talk or interference unless complex subtraction techniques are used [436, 439].

There is a strong linear relationship between EMG amplitude and the force developed in muscles which is why it is a useful measurement for biomechanical modelling [440]. This linear relationship is also essential to the concept of normalisation, because it allows the EMG amplitude to be expressed as a percentage of a fixed reference amplitude [440]. Normalisation of the raw EMG signal is required when it is to be compared with other EMG data either from other subjects or between experimental conditions [439], because factors such as skin impedance, electrode position, collection methods, electrode size and pick-up area can all potentially affect the amplitude of the recording [440]. The most common normalisation method involves the determination of a ratio between the measured EMG amplitude and the amplitude measured during a maximum voluntary isometric contraction of the muscle at a particular angle [441]. However, other methods such as dynamic and submaximal normailsation methods are also used [439]. One study found that submaximal contractions were actually more repeatable than maximal contractions [442].

Surface EMG therefore, is a useful tool for measuring the relative activation of superficial muscles. The signal however, must be normalised in order for it to be used in studies requiring comparison between experimental conditions. Although maximum voluntary isometric contractions are commonly employed in kinematic experiments, submaximal isometric contractions are also valid and may be more repeatable.

2.8. Assessment and classification of posture

2.8.1. Classifying posture

Human standing posture is considered to be balanced when the head, neck, trunk, pelvis and lower limbs all articulate in such a way as to maintain a stable posture with minimal energy expenditure [359]. Specifically, a sagittally balanced spine is one in which a plumbline dropped from the centre of the C7 vertebral body would pass through the posterior superior corner of S1, or between the posterior-superior corner of S1 and the hip joints [293] (Figure 2.30). However a balanced spine can still be abnormal. For example, a spine with an excessively large thoracic kyphosis combined with an excessively large lumbar lordosis might still be balanced [293].

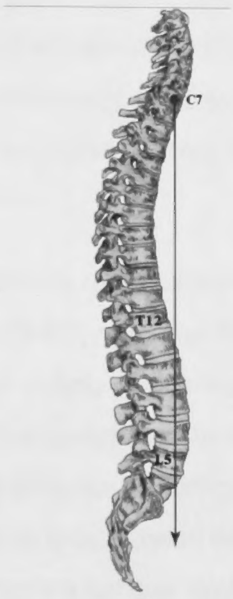

Figure 2.30. The C7-S1 plumbline. Sagittal spinal balance is determined by the relative position of the sacrum to a line dropped from the centre of C7.

Note. Adapted from Macagno, A.E. and M.F. O'Brien, *Thoracic and thoracolumbar kyphosis in adults.* Spine, 2006. **31**(19 Suppl): p. S161-70 with permission.

For this reason classifications of spinal posture which describe the shape of the sagittal curvature have therefore evolved. Staffel reported the first classification system in 1889 [443]. He divided sagittal spine posture into normal, flat, hollow, round, and hollow-round posture types (Figure 2.31). 'Round' is equivalent to thoracic hyperkyphosis while 'hollow' describes lumbar hyperlordosis. Goff (1952) later devised another very simplistic system which was more of a description of body shape than a postural classification system [444] (Figure 2.32). Another system which is commonly used by physiotherapists is that described by Kendall [445] (Figure 2.33). It divides posture into four core types: 'ideal', 'kyphotic-lordotic', 'flat-back' and 'sway-back'. Kendall also described a fifth type which he called 'lordotic' in which anterior pelvic tilt and increased lumbar lordosis are present without apparent alteration in thoracic or cervical curvature. These five posture types conform to Staffel's classification system with 'ideal' corresponding to'normal'; kyphotic-lordotic to 'hollow round'; 'flat back' to 'flat back', 'sway back' to 'round-back' and 'lordotic' to 'hollow back' (see Figure 2.31 and Figure 2.33). Therefore, although different terminology has been reported with some papers using Staffel's terminology [45] and others using Kendall's [446] the classification system is fundamentally the same.

Classification instruments specifically for the elderly have also been developed [379] for elderly posture. Ando (1986), and later Nakada et al. (2004) developed systems of classifying posture in elderly Japanese people [379]. The system devised by Nakada et al. (2004) showed excellent levels of agreement when assessed for inter-observer reliability and when compared with X-ray for discriminant validity [379]. Nakada's categories are similar to Kendall and Staffel's 'non-ideal' posture types apart from a lumbar kyphosis type which he calls 'hand-on-lap' which appears to be a progression or severe form of the 'flat-back' posture (Figure 2.31, Figure 2.33 and Figure 2.34). Neither Staffel's nor Kendall's postural classification system has been specifically tested for validity or reliability.

A classification system which includes the five posture types described by Staffel and Kendall, as well as the 'hands-on-lap' type (lumbar kyphosis) might arguably constitute a classification system capable of classifying both the young and very elderly.

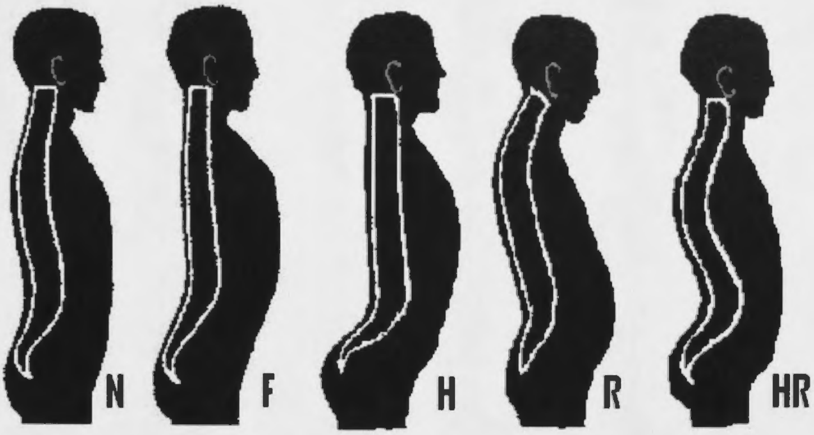

Figure 2.31 Staffel's posture classification.

Normal (N), Flat-back (F), Hollow-back (H), Round-back (R) and Hollow-round back (HR)

Note. Adapted from Beck, A. and J. Killus, *Normal posture of spine determined by mathematical and statistical methods.* Aerosp Med, 1973. **44**(11): p. 1277-81 with permission.

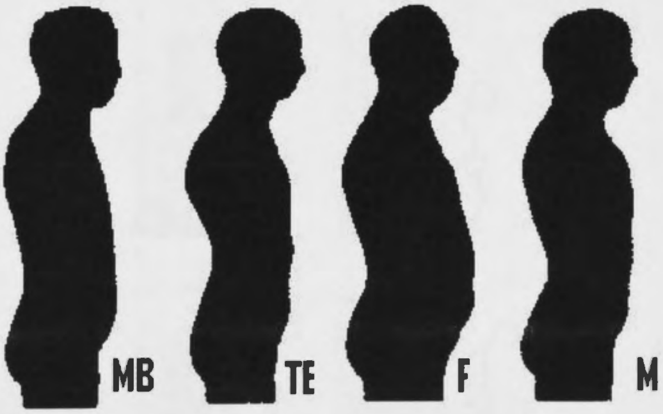

Figure 2.32 Goff's posture classification.

Muscular-balanced (MB), Thin-elongated (TE), Fat (F) and Muscular (M).

Note. Adapted from Beck, A. and J. Killus, *Normal posture of spine determined by mathematical and statistical methods.* Aerosp Med, 1973. **44**(11): p. 1277-81 with permission.

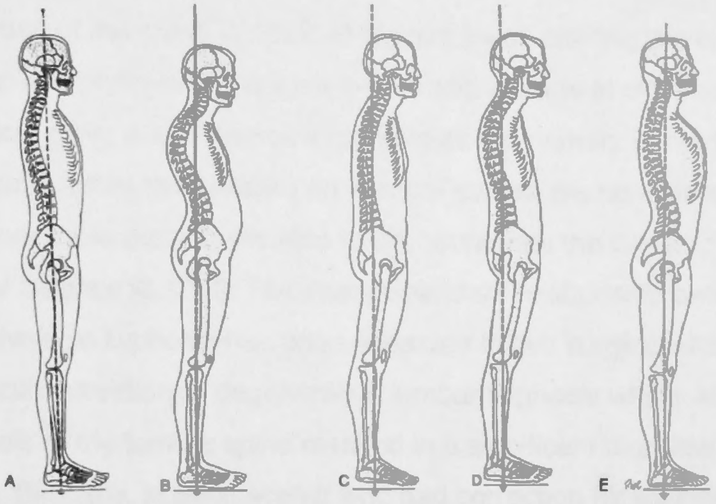

Figure 2.33 Kendall's five postural classifications.

A. Ideal; B. Kyphotic-lordotic; C. Flat-back; D. Sway-back; E. Lordotic.

Note. Adapted from Kendall, F., et al., *Muscles. Testing and Function with Posture and Pain.* 5th ed. 2005, Baltimore: Lippincott, William and Wilkins.

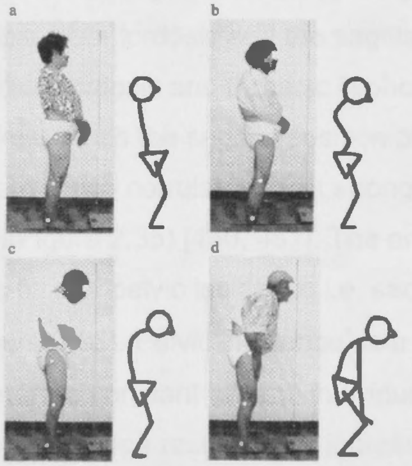

Figure 2.34 Nakada's senile posture classifications

a. Extended-type ; b. S-shaped ; c. Flexed-type ; d. Hand-on-lap.

Note. From Hirose, D., et al., *Posture of the trunk in the sagittal plane is associated with gait in community-dwelling elderly population.* Clin Biomech (Bristol, Avon), 2004. **19**(1): p. 57-63 with permission.

2.8.2. The relationship between the curves

Because of the need to retain spinal 'balance', altering the curvature in one spinal region is likely to result in a corresponding change in other regions [293, 359]. The thoracic curve is sometimes described as the primary curve because it is relatively immobile, while the lumbar and cervical curves are considered secondary because they are more mobile and able to accommodate the thoracic curve to maintain spinal balance [6, 293]. The inter-dependent relationship between lumbar lordosis and thoracic kyphosis has been observed in two surgical studies. A study of surgical correction of degenerative lumbar kyphosis which aimed to increase lordosis of the lumbar spine resulted in a significant increase in thoracic kyphosis [447]. Similarly, in adolescents who had correction for kyphoscoliotic deformity, a reduction in their thoracic kyphosis resulted in an unwanted decrease in their lumbar lordosis [448]. In contrast, a study of normal young French men and women failed to detect a clear relationship between thoracic kyphosis and lumbar lordosis [32] while another study which combined old and young subjects could only detect a weak relationship (r= 0.44) [449].

Lumbar lordosis is also fundamentally influenced by the pelvis. In fact, there is a better correlation between lumbar lordosis and the sagittal orientation of the pelvis than there is between lumbar lordosis and thoracic kyphotic angles [449, 450]. The orientation of the pelvis determines the sagittal position of the sacral plate and it is the angle of the sacral plate which correlates most strongly with the lumbar lordosis angle in standing (r=0.86)(Figure 2.35) [450, 451]. The angle of the sacral plate is determined by both pelvic tilt and pelvic incidence i.e. sacral slope = pelvic incidence – pelvic tilt (Figure 2.35). Pelvic incidence[*] is a fixed property of the pelvic anatomy and is therefore constant in each individual, while pelvic tilt can be changed. An increase in sacral slope results in an increase in lumbar lordosis. Thus, the degree of lordosis is influenced by both the anatomically-determined angle of pelvic incidence with which we are born, and the degree of pelvic tilt.

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[*] Pelvic incidence is defined as the angle between the line perpendicular to the sacral plate at its midpoint and the line connecting this point to the axis of the femoral heads.

Pelvic tilt correlates with the degree of lumbar lordosis (r=0.54 – 0.6 [450, 452]) but not as strongly as the correlation with sacral plate slope [450].

The relationship between the degree of thoracic kyphosis and the degree of cervical lordosis is less clear. Anecdotally, increased thoracic kyphosis is believed to cause a forward-head or poke-neck posture but a study of the standing sagittal posture of people aged between 17 and 83 years showed that this was not the case [368]. In sitting, however, the degree of kyphosis has been shown to correlate with increased forward lean of the neck (r= 0.44) and increased extension of the upper cervical spine (r= 0.41) [449] and slumped sitting has been shown to induce a forward head posture [453].

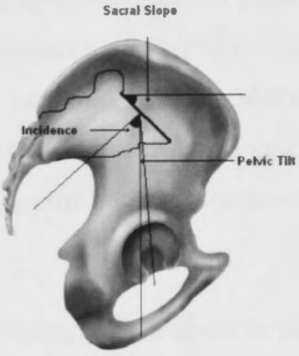

Figure 2.35. The pelvic angles. The pelvic parameters. *Pelvic incidence:* the angle between the perpendicular to the sacral plate at its mid-point and the line connecting this point to the middle axis of the femoral heads. *Sacral slope:* the angle between the superior plate of S1 and a horizontal line. *Pelvic tilt*: the angle between the line connecting the midpoint of the sacral plate to the axis of the femoral head and the vertical.

Note. Adapted from Legaye, J., et al., *Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves.* Eur Spine J, 1998. 7(2): p. 99-103 with permission.

2.8.3. The utility of postural classification

Classification of posture is an important part of clinical practice and clinicians draw certain conclusions about the cause and effect of different postural types based on sound assumptions and plausible mechanisms [445, 446]. However, there is very limited epidemiological information available to indicate the prevalence of the different postural types and their relationship with aging or with pain syndromes [446]. Smith et al. (2008) assessed thoracolumbar posture in 766 adolescents and identified four postural types: neutral, sway, hyperlordotic and flat [446]. The most common posture type in the adolescent study was hyperlordotic (30.2%), followed by neutral (25.6%), with approximately equal proportions of sway- and flat-backs (22.5% and 22.8%). In a study of 71 people aged between 65 and 84 years in Japan, Oi (2004) reported that 37% had normal (neutral) posture, 30% had flexed type (flat-back), 20% had S-shaped type (kyphotic-lordotic), 11% had extended type (sway-back) and 2% had hand-on-lap type. Although the data from these two studies are not directly comparable, it is interesting to note the absence of the kyphotic posture in the young group and the decreased incidence of hyperlordotic posture in the elderly group.

Although the epidemiology of aging with respect to postural classification is not well reported, it is possible to extrapolate from some of the reports which describe anatomical changes due to age. Thoracic kyphosis has been reported to increase with age with a concommitent caudal shift in the thoraco-lumbar inflexion point [35, 84]. This is most marked in females [35]. Increasing age is correlated with a more anterior sagittal vertical axis and loss of distal lumbar lordosis [52, 454];[76]. However an age-related loss of lordosis is not universally reported [449]. The loss of lordosis is seen in the sway- and flat-back posture types while lower inflexion points are seen in kyphotic-lordotic, sway-back and lordotic posture types (Figure 2.33). In an ex-vivo study, the cervical lordosis has been observed to flatten especially in males, and the inflexion point between the thoracic spine and the cervical spine has been observed to move cranially from T3 to C7/T1 [455].

Posture classification systems are a useful ‘shorthand’ way of relating potential causes of, or contributing factors to, painful symptoms and/or movement dysfunction. For example, better muscle strength in the spinal extensors has been associated with a larger lumbar lordosis and a smaller thoracic kyphosis [12] and hamstring tightness has been associated with decreased lumbar lordosis [445, 456]. Smith, O'Sullivan et al (2008) reported that sway-back posture was more problematic for adolescent males and flat-back posture was related to more sports-related pain in adolescent females [446]. Although posture classification systems do not replace the measurement of curvature described previously (2.6), they are a useful tool for clinicians, especially if the findings from more precise measurement modalities can be related to them.

2.9. Treatment of hyperkyphosis

The treatment of hyperkyphosis depends on the underlying pathology. Although osteoporotic fracture is a possible cause of hyperkyphosis, the shape of the vertebrae does not explain the entire curve [31, 233]. It has been suggested that other structures such as muscles, ligaments, discs and sub-optimal postural control mechanisms may also play a significant role and that some of these components may be remediable [9, 31].

If osteoporotic fracture is the cause then bisphosphonates, which decrease the risk of further fracture, are considered to be the first line of treatment [457]. However, long-term use of bisphosphonates has been associated with atypical fracture due to decreased bone turnover [458] as well as cancer of the oesophagus [459] and osteonecrosis of the jaw [460]. Where hyperkyphosis is severe, surgical management is becoming increasingly common [461]. However, because hyperkyphotic posture itself has been identified as an important risk factor for fracture independent of low bone mineral density (BMD) or fracture history [13], conservative treatment strategies are attracting more interest [221].

2.9.1. Vertebroplasty and kyphoplasty

Vertebroplasty was first developed in France in the late 1980s to treat spinal hemangiomas [462] and subsequently osteolytic metastases and myeloma [463]. It has since been used to treat painful acute vertebral compression fractures [464]. It involves the percutaneous injection of bone cement into deformed vertebrae in order to strengthen and stabilise them [461]. Kyphoplasty is a proprietory derivative of vertebroplasty which involves inserting a balloon into the vertebra to elevate the depressed vertebral end-plate before injecting the bone cement [465]. The aim of kyphoplasty is not only to stabilise the fracture but to reduce it [466]. Both procedures aim to reduce the pain associated with vertebral fracture and are usually performed under local anaesthesia, needing only an outpatient visit or a short hospital stay [461].

A plethora of studies have reported positive outcomes after both vertebroplasty and kyphoplasty in terms of pain relief, reduction in thoracic kyphosis and restoration of the mid-vertebral height [461, 467, 468]. Some studies have shown that, although vertebroplasty results in better outcomes in terms of cost effectiveness and pain relief in the first three months, there is evidence to suggest that, compared to conservative treatment, there are no long-term benefits [467, 469]. However, two recent randomized controlled trials (RCT) did not find any short-term or medium-term benefit from vertebroplasty for the treatment of symptomatic osteoporotic vertebral fractures, as compared with a single administration of a local anesthetic [470, 471]. In contrast, an RCT which compared kyphoplasty with conservative treatment demonstrated significant improvements in quality of life, pain and physical function in the surgical group compared to the control group [472]. However this study was industry funded and not blinded.

Possible complications of these procedures include leakage of the cement into surrounding tissues including the neural foramina resulting in severe nerve root pain [463] and subsequent fracture of adjacent vertebrae [473]. However, the incidence of complications is reported to be only around 1.6% for vertobroplasty and 0.3% for kyphoplasty [467]. Prophylactic injection of the adjacent vertebra superior to the fractured vertebra has been reported to result in a significant reduction in subsequent fracture rate [474].

In spite of the inconclusive evidence in their favour, vertebroplasty and kyphoplasty have become the treatment of choice for severe and acutely painful vertebral compression fractures [467] and kyphoplasty is held to be an effective method of reducing kyphotic deformity in severe cases of osteoporotic compression fracture [468]. However, preventing the evolution of such severe and painful deformity remains a significant challenge to health care professionals [19].

2.9.2. Conservative strategies

The 15 studies which have reported the effects of various conservative strategies on thoracic hyperkyphosis are presented in

Table **2.7**. Broadly, the interventions include postural re-education, strengthening, stretching, joint mobilization, and bracing. The majority of the studies have evaluated a mixed modality intervention which makes the effectiveness of individual modalities difficult to tease out. A few studies have reported reduced forward head posture (FHP) as a result of a targeted exercise programme [97, 475]. However, thoracic kyphosis angle has been shown to be uneffected to FHP [368] and so these studies are not included here.

2.9.2.1. Postural re-education

The remediation of poor postural habits with a view to reducing pain and improving function is a cornerstone of physiotherapy practice [2, 476]. The theoretical rationale for posture correction is that it reduces mechanical stress on joints and body tissues caused by distortions in posture resulting in changes in gravitational force distribution and muscle imbalance [445]. The relationship between hyperkyphosis and pain and/or disability has been discussed in 2.2.6. In spite of some conflicting evidence [84, 223] it is generally accepted that age-related hyperkyphosis is detrimental to function [19, 221]

The methods of promoting better balance and alignment are numerous and include exercise, stretching, proprioceptive training and ideokinematic imagery. Postural re-education could therefore include a number of interventions, but for the purpose of this discussion it is defined as the specific teaching of postural alignment with or without an accompanying exercise programme.

Table 2.7 Intervention studies for hyperkyphosis

Paper	Intervention	Subjects	Kyphotic angle method	BES testing method	Kyphotic angle results	BES testing results
Fairweather and Sideway 1993 [477]	8 weeks 3 X per week Randomisation not reported	20 females and 20 males Aged 18 - 23	Video- photometry marker position not reported	None	Ideokinematic - 6° males only	Not measured
Itoi and Sinaki 1994 [10]	2 years of resisted prone extension exs 30% of 1RM X10 per day 5 days per week RCT.	60 postmenopausal females Mean age 59	Cobb angle from lateral X-ray	Prone lying using the BID-2000	Control 0° change Exercise +1.6° change	Control 14.1 kg increase Exercise 26.6 increase
Schuerman 1998 [478]	Standing posture exercises RCT	48 post meno women with osteoporosis Aged 56 to 89	Inclinomery	Prone	No change	No change
Wang et al. 1999 [479]	6 weeks 3 X per week of shoulder girdle stretching and strengthening. Single group no control	9 males and 11 females mean age 30 with forward shoulder posture	Metrecom electrogoniometer	None	3.3° reduction in forward inclination of the upper Tsp	Not measured
Sinaki et al. 2002 [480]	See Itoi and Sinaki (1994)	50 postmenopausal females Mean age 57	Cobb angle from lateral X-ray	Prone lying using the BID-2000	Not reported. No sif diff between control and exercise group..	Control -10 kg Exercise -6 kg
Pfeiffer et al. 2004 [481]	6 months of wearing a thoracolumbar brace RCT	62 osteoporotic females with at least one vertebral fracture and kyphosis > 60° Mean age 73	Cobb angle from lateral X-ray	Seated isometric flexion	Control -1.6° Brace -7.9°	Control +189 N Brace +7 N

*Note.*BES = back extensor strengthening; RCT = randomised and controlled.

Table 2.7 continued

Paper	Intervention	Subjects	Kyphotic angle method	BES testing method	Kyphotic angle results	BES testing results
Gold et al. 2004 [424]	6 months multimodal stretching and strengthening exercises Randomised modified crossover	185 postmenopausal females with VFs Mean age = 81	None	Seated extension using the B-200 isostation ?lumbar or thoracic ext	Not measured	3.6 – 6.6 foot lb change in torque but not sustained over 6 months
Renno (2005) [482]	8 weeks 3 X per week of prone extension exercises, general fitness and breathing exs Single group no control	14 osteoporotid women Mean age 69	Photometry with markers on C7 and T12	None	3° or 5% reduction	Not measured
Vaughn 2005 [96]	12 weeks 4 X per week of strengthening and stretching home exs RCT	71 males and females		None	No changes	Not measured
Sinaki et al. 2005 [95]	4 weeks daily strength and mobility exercises with a brace (SPEED programme)	25 osteoporotic females Mean age 71	Cobb angle from lateral X-ray	Prone lying using the BID-2000	Not reported	SPEED programme + 53 N
Katzman et al. 2007 [8]	12 weeks X2 per week multimodal stretching and strengthening exercises Single group no control	21 females with kyphosis of 50 degs or over Mean age 72	Debrunner kyphometer Tragus to wall	Seated Isometric peak torque to body weight expressed as a %	kyphometer -6º usual -5º best Tragus to wall No sig diff	21+/-13% change between before and after

*Note.*BES = back extensor strengthening; RCT = randomised and controlled.

Table 2.7 continued

Paper	Intervention	Subjects	Kyphotic angle method	BES testing method	Kyphotic angle results	BES testing results
Greendale et al. 2009 [9]	3 months 3X per week of Yoga. RCT	118 subjects 81% women Mean age76	Debrunner kyphometer Flexicurve (angle)	None	Kyphometer change Control -1.33° Yoga -3.00° Flexicurve angle change Control 0.82 Exp Grp -0.93	Not measured
Ball et al. 2009 [98]	1 year of multimodal stretching and strengthening exercise Single group no control	50 females aged 50-59	Kypholordometer (spine board)	None	Area under the curve decreased by 12 cm^2 in compliant subjects	Not measured
Kuo et al. 2009 [452]	10 weeks 2 X per week of Pilates exercises Single group not controlled	10 males and 24 females Mean age 64	Video photomety with markers on T1, T9, T11 and L1.	None	2.3° reduction	Not measured
Emery et al. 2010 [100]	12 weeks 2 X per week RCT	10 females and 9 males healthy young. Mean age 30 years	Vicon motion analysis with markers on C7, T6 and T12	None	Control +0.3° Pilates -5°	Not measured

*Note.*BES = back extensor strengthening; RCT = randomised and controlled.

Many papers have been published which recommend a variety of exercises aimed at improving kyphotic posture [483-489]. The advice contained within these papers is based on the sound clinical principles of teaching better proprioceptive awareness as well as stretching anterior structures and activating extensor muscles. However, evidence demonstrating any efficacy of postural re-education in isolation is sparse. Those intervention studies which have specifically evaluated the effect of conservative intervention on thoracic angle reflect clinical practice in that they are multimodal i.e. the intervention includes stretching strengthening and postural re-education. It is therefore difficult to determine the specific effect of the postural re-education component. There are, however, two studies which have, more or less, evaluated postural re-education alone [477, 478].

Fairweather and Sideway (1993) randomised a group of young men and women to either ideokinematic imagery with abdominal strengthening and flexibility exercises or control [477]. The ideokinematic technique involved heightening the subject's awareness of their spinal posture with a number of visualizations for 15 minutes, three times a week for three weeks. The males in the ideokinematic group significantly reduced their kyphosis by 6° from a mean of 33° and reported that their low back pain had ceased. The females and the groups which received abdominal strengthening and flexibility exercises also improved but the change did not reach significance (the raw data were not reported) and the reduction in back pain was only transient. No follow-up reports of the effects of this technique have been published.

Schuerman (1998) evaluated the efficacy of standing postural exercises in a controlled study of post-menopausal women. She found that a 12 week home programme of daily exercises did not result in a significant decrease in kyphotic angle or an increase in back extensor strength [478].

2.9.2.2. Strengthening

Whether back extensor strengthening reduces thoracic kyphosis has not really been established in spite of a considerable body of literature which tries to argue to the contrary. It is important to be clear that there is a difference between the finding of an association between back extensor strength (BES) and kyphotic angle and the demonstration that strengthening decreases kyphotic angle in the context of a prospective study. A number of authors have reported an association [10-12] while others have failed to delect an association [322]. Some studies have reported a relationship between BES and range of movement rather than kyphotic angle per se [283, 321]. Two studies reported that BES is increased after prone back extension exercises [490, 491]. However, the only randomised controlled trial which prospectively set out to evaluate the effect of prone extension exercises on kyphotic angle in post-menopausal women failed to demonstrate their effectiveness [10]. The authors found that after 2 years of extension exercises in prone lying there was no difference between exercise and control group in terms of thoracic angle. In a post hoc analysis the authors retrospectively subdivided their cohort into two arbitrary groups based on how much their BES had increased over the 2 years. Twenty seven women were allocated to the stronger group (increase ≥ 21.1 kg) and 33 to the weaker group (increase in BES < 21.1 kg). They then looked at the groups as a function of more or less kyphosis. They found that, amongst the subjects with substantial kyphosis (i.e. > 34.1°), those with a significant increase in BES had a significant decrease in thoracic kyphosis (-2.8 ± 4.2°; $p = 0.041$) while the rest did not. They concluded that *"increasing the back extensor strength in healthy oestrogen-deficient women helps decrease thoracic kyphosis*" though their data do not justify this statement. While a relationship between strength and kyphotic angle may have been detected, prone back extension exercises themselves were not shown to have any significant effect. An 8 year follow up of most of the subjects in the trial showed that the BES of the exercise group was significantly greater than that of the control subjects. This supports the efficacy of the programme in increasing BES but not in decreasing kyphosis.

Whether back extension strengthening exercises can reduce kyphotic angle in adults is therefore still not known. It is possible that adult erector spinae muscles deteriorate over time and are thus not amenable to strengthening. A cross-sectional study of subjects aged between 20 and 89 years found that BES reduced with age after a peak in the 4th or 5th decade. However, it has been reported that even though it is attenuated by age, strength training is still effective in older people [492].

Although the bulk of the literature related to back extensor strengthening and kyphosis has involved prone lying extension exercises and measurement, extension exercises can also be undetaken in a sitting position [8, 11, 424, 481]. The reliability of testing extension strength in prone lying has been reported to be high [423] but the reliablility of seated extension-strength testing has not yet been tested. The advantage of seated extension exercises and testing compared to prone lying is that frail elderly people and those with disabilities are more able to assume this position [11]. Extension from prone lying is more difficult than from sitting and the potential for a floor effect is unlikely in the sitting position whereas it is very likely in a cohort of weak elderly people in prone. However, in a sitting position body weight is likely to be an advantage in terms of the potential force output because the weight of the torso itself contributes to the overall extension force measurement. One group has overcome this problem by normalising the seated BES measures by dividing the forces measured by body weight [8]. There may be significant kinematic differences between prone and sitting extension exercises with respect to the thoracic spine, but these dfferences have not yet been investigated.

2.9.2.3. Stretching

Passive muscle stretching is believed to be beneficial in that it reduces injury risk, relaxes hypertonic muscles, and lengthens shortened tissue [493]. Stretching is also used to improve postural alignment [479, 494, 495] [486]. However recent research has questioned whether passive stretching is as effective as has been previously thought.

The role of stretching in postural realignment is to lengthen the tissues and possibly to improve joint position sense [496]. A systematic review of studies which examined the effect of stretching on increased muscle length concluded that there was moderate evidence to suggest that passive stretching did increase range of movement for more than one day after cessation of stretching [497]. However a recent study has suggested that a sustained increase in range depends on how the stretch is performed [498]. In this study, passive stretching was compared to strengthening in a lengthened range. Strengthening in a lengthened range was found to produce a shift in the torque-angle curve indicative of an increase in muscle length whereas passive stretching did not [498]. The authors concluded that passive stretching resulted in an increase in stretch tolerance rather than a true change in length. This finding supports previous reseach which found that the 'contract-relax' neuromuscular facilitation technique produced significantly more muscle lengthening than the other techniques [493].

Tightness of the pectoral muscle is believed to be associated with increased kyphosis [479]. Although pectoralis major stretches are described in many studies, it is pectoralis minor that directly influences the position of the scapula, acting with serratus anterior to draw the scapula forward around the chest wall. In conjunction with the rhomboids and levator scapulae, it downwardly rotates the scapula, depressing the tip of the shoulder [107]. The relationship between pectoralis minor and kyphosis is further supported by a study which found that people who had shorter pectoralis minor muscles were significantly more kyphosed [71]. A study which assessed the effects of pectoral stretch combined with resisted scapular retraction (3 times a week for 6 weeks), found that the angle of the upper thoracic spine significantly increased in verticality by a mean of 3.3° [71, 445, 479]. It is uncertain however, which of the elements of this intervention was most influential.

2.9.2.4. Bracing

Bracing for Scheuermann's kyphosis in juveniles has been in common practice since before 1965 [499]. Reduction in kyphosis of up to 40% has been reported [499]. In recent years, the use of bracing for severe kyphosis related to osteoporosis has yielded surprising results. A study of 12 elderly people who had just 4 weeks of proprioceptive retraining and back strengthening exercises combined with a weighted kypho-orthosis (brace) resulted in increases in BES of over 50N (27%) [95]. Another randomised controlled study of 62 osteoporotic women with severe hyperkyphosis found that bracing alone significantly increased back extensor strength by 73% and reduced kyphotic angle by 11% [481]. The use of bracing for non-osteoporotic age-related kyphosis has not been reported.

2.9.2.5. Joint manipulation and mobilisation

The treatment of thoracic spine pain and dysfunction with manipulation and mobilisation techniques is well documented [500]. A reduction of thoracic extension, as is seen in thoracic kyphosis, is reported to be due to a limitation of inferior glide at the zygoapophyseal joints [115]. Stiffness in response to cyclic posterior-anterior (PA) joint mobilization pressures is correlated with decreased joint range of movement in the mid-thoracic spine [501] which supports the use of this type of mobilisation to increase range. However, directing a force at an angle to the surface has been reported to result in negligible force transfer to the joint because of a lack of friction at the interface between skin and fascia [502]. No studies have evaluated the efficacy of the various accessory mobilisation techniques in the reduction of kyphosis but they have been reported to reduce pain [503, 504]. The efficacy of 'physiological' (as opposed to accessory) joint mobilisation was recently evaluated in an RCT [367]. Forty eight post-menopausal osteoporotic women with hyperkyphosis underwent a programme consisting of 18 sessions of physiotherapy over 3 months in which passive assisted physiological movements including extension in sitting, combined extension and rotation and/or side flexion as well as taping and postural stretching exercises were assessed. In the women who received treatment, kyphosis in sitting significantly reduced by 3.4° ($p = 0.017$) compared to an increase of 2° in controls. This degree of improvement was comparable to other conservative intervention studies (

Table **2.7**). Unfortunately it is difficult to separate the effect of the mobilisation technique from the other interventions. Taping has been shown to decrease kyphosis while *in situ* (see below) [366] and, as above, postural exercises have also been shown to reduce kyphosis [8].

2.9.2.6. Biofeedback

The use of auditory biofeedback for the correction of kyphosis in adolescents has been shown to be extraordinarily effective with a 17° reduction in kyphotic angle and complete resolution of postural abnormality after 10-12 months in some subjects [505]. Other biofeedback devices have been devised for the purpose of improving posture [371, 506] but, to date, no reports of their effectiveness in treating kyphosis in older adults has been published. Therapeutic taping could actually be considered to be a form of biofeedback. The previously-mentioned study which evaluated the effect of taping on thoracic kyphosis in 14 osteoporotic women found that the application of therapeutic tape reduced the kyphotic angle by 3°, but this difference was not sustained after the tape was removed [366]. Electronic biofeedback devices could be very effective at treating age-related kyphosis but they have not been widely used, possibly because of cost issues and lack of availability. Taping, however, is more commonly used by physiotherapists for the correction of posture.

2.9.2.7. Multimodal intervention programmes

In studies which have examined the effect of a multimodal approach to treating hyperkyphosis, postural re-education, stretching and strengthening are almost always components but bracing is occasionally included (

Table **2.7**). These multimodal studies have generated mixed results, some reporting decreases in kyphotic angle of between 2° and 6° [8, 9, 98, 100, 367, 482]) while others reported no significant changes [96, 452]. One study reported reductions in thoracic angle of 5° - 6° which was much greater than those reported in the other studies [8]. In addition, the 12 month follow-up of this study indicated that the 'best kyphosis' measurement improved further in the study participants who had independently continued to follow their exercise programme [507]. This study, however, was neither randomised nor controlled and so the results are potentially overstated. Another much larger randomised and controlled study looked at the effect of yoga on kyphotic angle and reported much more modest changes [9]. The differences were only significant in the secondary measure derived from flexicurve measurements but not from those derived from the kyphometer in which the yoga group showed a median of 3° reduction compared to the control group in which the angle reduced by a median of 1.3°. Other studies have reported postural improvements using various measurement modalities which are difficult to compare. Emery et al (2010) evaluated the effect of a 12 week Pilates programme in young adult males and found that the angle from the vertical made between T1 and T12 reduced by 5° in the experimental group while it increased by 0.3° in the control group [100]. This reduction in angle is large by comparison to most of the other studies, but there are two possible reasons for this. First, the cohort was young and therefore possibly more amenable to change; second, the measurement used was not strictly a measure of kyphosis and is, therefore, difficult to compare with other measures. Another study which evaluated a 10 week Pilates programme in older adults reported no significant difference in the angle measured at baseline and after completion of the programme [452]. In an uncontrolled study of 14 osteoporotic women who undertook 8 weeks of strengthening, stretching, postural re-education, walking and respiratory exercises the mean kyphotic angle reduced by 3° representing a 5% decrease [482]. However a controlled trial which evaluated the effect of stretching and strengthening exercises commonly prescribed by physiotherapists to reduce kyphosis and improve posture resulted in no significant differences between the control and expermental group [96]. Ball et al. (2009) claimed that a programme of multiple back extension exercises (performed three times a week for 1 year) significantly improved thoracic posture in women between 30 and 79 years [98]. This study was, however, neither controlled nor randomised: the comparison was made between subjects who were compliant with the programme, and those who were not.

It is clear, therefore, that although there are methodological problems with some studies, some multimodal exercise programmes[*] seem to be effective in reducing thoracic kyphosis, but some are more effective than others and some are not effective at all. Although the reason for the differences may lie in factors such as age, gender and extent of kyphosis [10, 96], some individual intervention modalities such as postural re-eduction, strengthening or stretching, may be more effective than the others..

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[*] Yoga and Pilates are included under this heading because they potentially employ stretching, strengthening and postural re-education.

2.9.2.8. Summary

The literature has revealed that various strategies for reducing hyperkyphosis have proved to be effective. However, although there have been a number of studies in older people, only prone back extension exercises have been evaluated in isolation [10] and these were not effective. It is, therefore, difficult to ascertain whether one intervention is more or less efficacious than another or whether they interact with each other to achieve a better effect. The issue of what constitutes a clinically relevant reduction in kyphosis has not been widely discussed in the literature. Spinal surgeons, who use successive Cobb angle measurements from lateral X-ray, have nominated a 5° change to be clinically meaningful (2.6.2.1). However, the studies presented in this section have reported more modest effects of 3° to 5°. Using statistical comparison to ascertain the significance of a treatment effect is valid, but clinical relevance cannot be overlooked. Larger angular improvements may be possible in older people but, because the isolated effects of individual intervention strategies have not been assessed, it is difficult to know how to adjust intervention programmes to produce greater and, perhaps more clinically relevant, improvements. Also, the efficiency with which the intervention is delivered is important for both the clinician and the patient. More knowledge about the individual therapeutic advantages of the various therapeutic strategies could lead to more time-efficient treatment programmes which are more palatable to the general public and, therefore, potentially more sustainable and effective.

2.10. Stroke

2.10.1. Definition

The World Health organisation defines stroke as "rapidly developing clinical signs of focal (at times global) disturbance of cerebral function, lasting more than 24 hours or leading to death of no apparent cause other than that of vascular origin" [508]. A stoke is caused by a disruption of the blood supply to the brain, usually by a blood clot or a haemorrhage, which cuts of the oxygen and nutrient supply to the area affected causing damage to the brain tissue [509]. The most common symptom of stroke is weakness or numbness of the face, arm or leg on one side of the body [509]. Although other symptoms such as visual loss, sensory loss, double vision, speech difficulties , confusion and dizziness can also occur [509] it is the motor deficits which are of primary interest in relation to posture and hence this thesis. The effects of stroke depend on which part of the brain is and how severely it is injured [509].

2.10.2. Anatomy

The area of the motor cortex (Figure 2.36) which controls the trunk is situated superiorly over the cerebral convexity (Figure 2.37). Cortical projections to the trunk muscles have been reported to emanate from both hemispheres [510] and the primary sensory cortex serving the trunk lies just behind the motor cortex and has also been shown to have bilateral projections [511]. Corticospinal control of the trunk muscles has a strong ipsilateral component in contrast to the limb muscles which are almost entirely controlled by contralateral projections [512]. These ipsilateral projections have been shown to be assymetrical, but hemispheric dominance is equally represented in a cohort of normal subjects and does not correlate with handedness [512]. The latency of impulses reaching the trunk via the ipsilateral fibres is longer than that of the contralateral projections because they descend in the slower anterior corticospinal tract as opposed to the faster lateral corticospinal tract [512]. The bilateral nature of the projections to the trunk therefore diminishes the effect of stroke on the trunk as compared to its effect on the limbs which are almost entirely supplied by one hemisphere. However, clinical studies have shown that trunk movements, particularly extension, are significantly weaker in people after stroke than they are in normals [513]. This weakness is potentially due to an inability to recruit high-threshold motor units due to the general reduction in cortical drive [513].

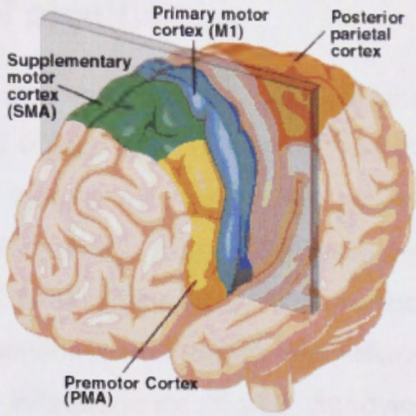


Figure 2.36 Principal cortical domains of the motor system. The primary motor cortex (M1) lies along the precentral gyrus, and generates the signals that control movement. Secondary motor areas are involved in motor planning.

Note. Picture sourced from http://brainconnection.positscience.com/topics/?main=anat/motor-anat

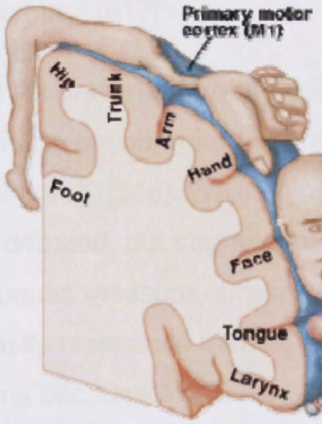


Figure 2.37 The motor homunculus in primary motor cortex. A figurative representation of the body map encoded in primary motor cortex.

Note. Picture sourced from http://brainconnection.positscience.com/topics/?main=anat/motor-anat

2.10.3. Clinical significance

Over 50 000 strokes occur every year in Australia. Many people survive meaning that approximately 322,000 people per year are affected by stroke in Australia. Approximately 42% of these people have a disability and people with stroke are more likely than any other diagnostic group to have severe or profound core activity limitation [514]. Broadly speaking, rehabilitation for people with stroke aims to increase their independence and reduce their reliance on support services. The restoration of physical independence through improving physical function is a key element in this process. Stroke affects the trunk as well as the limbs [15] and good trunk control has been shown to be significantly correlated with better overall performance in activities of daily living [515].

The functional organization of the cerebral cortex is plastic and changes occur throughout life in response to trauma, pathological changes, learning and manipulation of sensory experience, [516]. Physiotherapists utilise this plasticity to achieve changes in motor control [517].

The stroke guidelines from the National Stroke Foundation (Australian) recommend that "*stroke survivors should be encouraged to participate long term in appropriate community exercise programmes*" [518]. Which type of exercise should be recommended is still hotly debated, but strengthening is re-emerging as a potentially beneficial therapeutic measure for people with stroke. Historically, strengthening or high-intensity resistance training has been excluded from neurorehabilitation programs because of the concern that high-exertion activity, including resisted strengthening, would increase spasticity [519]. However, despite limited long-term follow-up data, three systematic reviews have found that there is good evidence to support the belief that resistance training produces increased strength, increased gait speed, improved functional outcomes and improved quality of life without exacerbation of spasticity [519-521]. Scheets et al (2007) suggested that the movement dysfunction which is seen in stroke can be classified into three categories: force production deficit, fractionated movement deficit, and perceptual deficit [522]. For those whose deficit is due to an inability to produce sufficient force to function normally, strengthening is emerging as an appropriate intervention

[522]. To date, the trials which have evaluated strengthening post stroke have examined the effects of both limb strengthening and general fitness programmes [523-527] but there has not yet been a trial evaluating the effects of progressive resisted back strengthening exercises in people with stroke.

Effective control of the trunk is an essential component for balance and efficient movement in the upright position [528]. Trunk control scores correlate with measures of function (such as walking velocity) and they have been reported to account for 52% of the variance in length of stay in hospital after stroke [529] and 45% of the variance in ability to perform activities of daily living [530]. In people with stroke, recruitment of the both erector spinae muscles and the abdominal muscles has been shown to be slower [531] and weaker [513] on both the affected and non-affected sides during activities requiring postural adjustment. Further, trunk control has been shown to be impaired well into the chronic stage of stroke [532], and trunk repositioning errors in people with stroke have been reported to be double those of age matched controls [533].

In spite of the obvious importance of normal trunk control, there have been no trials to date which have attempted to evaluate the effect of progressive resisted back extension strengthening exercises on the strength and functional performance in people with chronic stroke.

2.10.4. Summary

Stroke is a condition which affects a significant proportion of older adults and some younger ones. Successful rehabilitation after stroke requires that effective measures are taken to ensure that the person affected by stroke achieves the best motor potential possible in order to function as independently as possible. Effective control of the trunk is essential for effective limb control and balance. Trunk weakness following stroke is especially apparent in the extensor muscles. Progressive resisted exercise has been shown to be effective in the limb muscles but its effect on trunk extension has yet to be investigated.

2.11. Summary of the literature review

The increased kyphosis, or hyperkyphosis, which has been observed to occur with increasing age, is not only caused by osteoporosis but is more often due to bony remodelling and disc degeneration. An increase in kyphosis dramatically increases the load, and hence compression force, on the anterior aspects of the vertebral bodies. Because the osteoporosis which occurs in later life results in a depleted trabecular bone network, the increased forces present in a kyphosed spine are even more likely to result in bony collapse. Prevention of hyperkyphosis in the adult at all ages is therefore an important healthcare challenge.

Although the measurement of thoracic kyphosis has traditionally been achieved using a Cobb angle derived from a lateral x-ray, non-invasive methods have also been developed. Most are clinic measures like the Cobb angle, but dynamic measurement devices are becoming more accessible. The flexible electrogoniometer is a potentially useful device because it is able to be used in all (non-aquatic) environments and can measure both angular displacement and movement frequency. Its use has not yet been thoroughly validated in the thoracic spine.

Treatment of hyperkyphosis has been investigated largely in the post-menopausal female population. The evidence to date indicates that some multimodal programmes which incorporate strengthening, stretching and postural re-education are modestly, but significantly, effective. However, the fact that not all studies show this, points to the fact that the individual elements of the programmes may have differential effect. Differentiating between the effects of the various treatment approaches would shed some light on why some programmes are more effective than others. However, it is important to establish which strategies are currently being employed clinically in order to ensure that research is related to, and meaningful to, clinical practice.

Reduced BES is believed to be related to increased kyphotic angle but exercises in prone lying did not result in a reduction of thoracic kyphosis in post-menopausal women. Although back extensor strengthening in prone lying has not yet been established as an effective measure, strengthening exercises in other positions have not yet been thoroughly tested. Biomechanically, retraction of the scapulae using the middle fibres of trapezius potentially stiffens the thoracic spine and enhances the effect of the thoracic erector spinae. These muscles may be better recruited in a sitting position. Although some studies have assessed BES in sitting, a comparison of the two positions has not yet been conducted.

Stroke is a condition which can result in catastrophic physical disability but more often leaves people with moderate disability rendering them less able than their non-stroke affected peers but still able to live in the community. Problems with trunk control have a marked effect on the functional independence of people with stroke. Loss of extensor muscle strength has been shown to be particular feature. A hyperkyphotic posture in people with stroke affects the biomechanics of the spine in the same way it does in people not affected by stroke, but the ability to adapt may be markedly reduced. Although strengthening exercises have been shown to be effective in people with stroke in terms of improving function, back extensor strengthening has not been assessed.

The specific aims of this thesis have been stated in chapter 1 and the following chapters describe the individual studies which were conducted to fulfill these aims.

Chapter 3.

Validation of the Flexible Electrogoniometer for Measuring Thoracic Kyphosis

This chapter has been published as Perriman, D.M., et al., *Validation of the flexible electrogoniometer for measuring thoracic kyphosis.* Spine (Phila Pa 1976), 2010. **35**(14): p. E633-40.

3.1. Introduction

Thoracic kyphosis is defined as the primary sagittal spinal curve between T1 and T12 [119]. It is commonly accepted that the normal upper limit of thoracic kyphosis is 40° when measured from the vertebrae at the top and bottom of the curve [20, 534]. Although thoracic kyphosis exceeding the normal range can be present at all ages, it commonly increases with age leading to a higher prevalence in the elderly [1, 20, 30]. Although increased kyphosis is a common feature of osteoporosis it also presents in people with no change in bone mineral density [21]. Further, there is some evidence to suggest that the incidence of osteoporotic fracture may be increased by pre existing kyphotic deformity [13]. An increase in kyphotic curve can cause pain and disability [61] respiratory compromise [62]. and may also contribute to falls in the elderly [63]. The extent of the problem in older people is significant. Bartinski et al. (2005) reported that 50% of males and 65% of females over the age of 65 have increased kyphosis [30]. The effective treatment and prevention of thoracic kyphosis is therefore an important healthcare challenge and effective measurement modalities are clearly essential to assess the efficacy of any potential therapeutic intervention strategies.

There are several possible methods of measuring thoracic kyphosis. The standard method is the Cobb angle [26, 39]. This is measured from a lateral X-ray as the angle subtended by the vertebral endplates above and below the curve [25]. This method is favored by clinicians because of its simplicity: the angle can be measured without the need for other complex and time-consuming assessments. Nevertheless, for the Cobb angle to be a useful clinical tool it must be reliable i.e. it must generate the same measured angle when applied to the same X-ray on multiple separate occasions. Accordingly, a number of groups have investigated its reliability [26, 33, 35, 39, 332, 349]. Most have found it to have very good intraobserver reliability in terms of relatively small mean differences between the measurements. However, it is important to note that while the reported mean angular differences were relatively small the individual differences could be as large as 30° which could obviously result in significant clinical error [332]. The primary source of error seems to stem from a lack of clarity on the X-ray images from which the angles are calculated [35, 332] but error may also result from using inaccurate protractors and drawing implements [332]. The use of the Oxford Cobbometer, which does not rely on drawing lines to measure the angle, has been reported to reduce intraobserver variability by nearly 50% [535]. It is also worth noting that the Cobb angle can potentially overestimate the angle of curvature because it is fundamentally influenced by the tilt of the endplates at the top and bottom of the curve, regardless of what occurs in between [233]. This may be a particular issue in older people [39].

Other radiological methods have been developed to replace the Cobb angle [35, 55, 358] but it remains the standard clinical measure and the measurement against which other more novel methodologies are usually compared [39, 536].

In addition to other measurements derived from the lateral X-ray [35, 55, 358], other non radiographic tools have been developed including the pantograph [537], the Arcometer [414],inclinometers [3], Dubrunner's kyphometer [339],the spinal mouse *[46],* and the flexicurve [28]. The non radiographic tools measure the curvature of the back at the skin surface and thus have the considerable advantage of being non-invasive enabling repeated measurement without subjecting the patients to radioactive exposure. Importantly however, all the above methods are only capable of static measurement and so may reflect "best" behavior rather than "normal" behavior. They cannot be used to measure angular change during dynamic activities or be used to make measurements independent of the examiner.

Several different systems have been devised which are capable of measuring dynamic thoracic spine movement [343, 538]. However, the only dynamic device which can record angular motion outside the laboratory is the Biometrics flexible electrogoniometer (FEG) (Biometrics, Cwmfelinfach, Gwent, UK). The FEG allows continuous measurement of the angular displacement between two lightweight plastic end-blocks at either end of a coil containing two strain gauges mounted at 90° to each other [380]. The FEG has an accuracy within ±1° [413] and has been used extensively to measure the angles of limb joints during functional activities [408]. One group has used it to measure the thoracic spine [418, 419], but a thorough validation of the FEG as applied to the thoracic spine has not yet been undertaken. Indeed, the question of which vertebral segments are being measured has not yet been addressed. This is important because the end-blocks on either side of the strain gauges are long enough to span two, or even three, vertebrae.

Accordingly, we set out to examine the accuracy, test-retest reliability and concurrent validity of the FEG when used to measure sagittal thoracic spine angle. When looking at concurrent validity we also wished to discover which part of the FEG end-blocks correlated most closely with the measured Cobb angle.

3.2. Methods

Three experiments were undertaken. First, a bench test of FEG accuracy; second, an investigation of test-retest reliability measuring kyphotic angle during seven activities; and, third, an investigation of concurrent validity comparing FEG angle to corresponding Cobb angles.

Ethics approval for this study was granted by the ACT Health Human Research Ethics Committee and the Australian National University Human Research Ethics Committee.

Table 3.1

Sample characteristics for test-retest reliability and concurrent validity experiments

	Test-Retest Reliability (Experiment 2)	Concurrent Validity (Experiment 3)
Number (M:F)	12 (4:8)	12 (6:6)
Age: mean (range) yrs	40.7 (25-61)	68.1 (50-80)
Weight: mean (range) kg	70.9 (50-95)	75.8 (62-94)
Height: mean (range) cm	170.0 (156-186)	171.2 (160-190)

3.2.1. Experiment 1: Bench test.

The FEG was bench-tested using a hinged plastic frame. The base of the frame was secured to the bench top with tape and the FEG (SG150) was zeroed against a ruler on a flat table surface. The FEG end-blocks were then secured to the arms of the frame so that the centre of the coil was over the hinge joint (Figure 3.1). This application was intended to simulate a flexion/extension movement in the sagittal plane. A plurimeter (Australasian Medical & Therapeutic Instruments P/L, Queensland, Australia) was secured to the upper arm of the frame. The plurimeter is a circular device which acts like a spirit level and is designed to measure angular change. 'Zero' was arbitrarily defined as the position when the arms were aligned in a vertical position. The upper arm of the frame was then moved in 10º increments from this point to +60 º of flexion and returned to -10º of extension. The angle measured by the FEG was recorded using the Biometrics Datalink and Biometrics software (version 2). This measured FEG angle was then compared to the angles measured by the plurimeter and the degree of correlation assessed by a Pearsons correlation coefficient (Data Analysis, below).

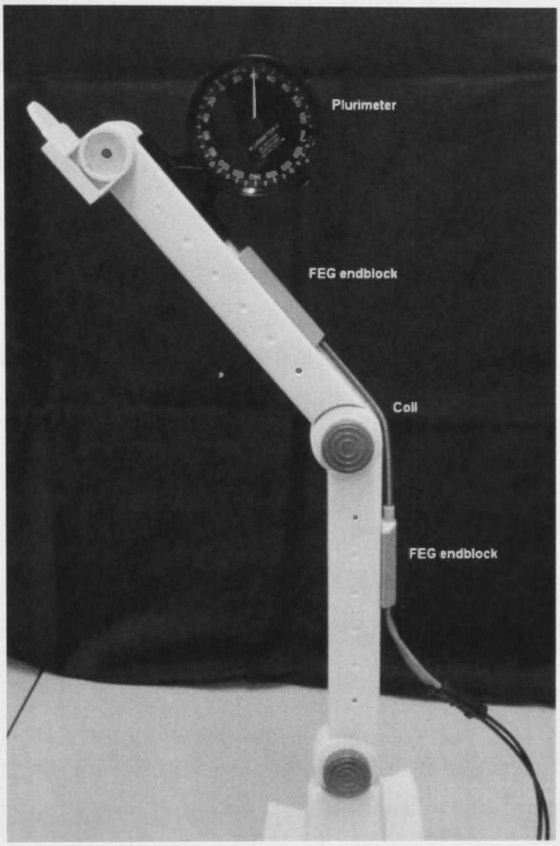


Figure 3.1 Bench test apparatus. The flexible electrogoniometer (FEG) was mounted over the hinge with the plurimeter mounted above. The hinge was moved from -10° to 60° according to the plurimeter and the FEG angles were recorded.

3.2.2. Experiment 2 – Test-retest reliability.

Twelve subjects (Table 3.1) were asked to perform seven functional activities one week apart. These subjects represented a sample of convenience recruited from posters calling for volunteers in a hospital. After zeroing, the FEG end-blocks were secured 12 cm above and below the T6/7 interspinous space determined by palpation. FEG recordings were made while each subject performed the following activities in this order: standing erect, standing relaxed, reaching for the ceiling, reaching for their toes with knees straight, reaching for a line drawn on a board at shoulder height and an arm's length in front of them, taking a deep breath (in standing), and walking on the spot.

For the purposes of analysis, a single measure for each of the seven activities was derived from a mean of the FEG output during the middle five seconds of each activity. A second identical measurement session took place one week later. The repeatability between week 1 and week 2 was calculated using an intraclass correlation coefficient ($ICC_{2,1}$) for each activity. An overall $ICC_{2,1}$ was then derived by averaging the results for all seven activities (Data Analysis, below).

3.2.3. Experiment 3 – Concurrent validity

Twelve normal subjects aged over 40 years (Table 3.1) were recruited via community posters. Older subjects were deliberately recruited for this experiment because we were interested in measuring kyphosis in an older population. The FEG was attached to the subjects' backs and stainless steel ball bearings were applied to the outer margins of each FEG end block in order to ensure that they would be visible on X-ray (Figure 3.2).

Lateral spine X-rays were taken of the subjects standing with their left side against a grid. Two X-rays were taken of each subject: one in erect standing with arms supported at 90° of shoulder flexion on a custom-built Perspex tray, the other in slumped standing with hands resting on the same tray which was lowered to waist height. The entire spine from the base of the skull to the sacrum was captured with the centering point at the level of the T7 vertebral body. A wedged aluminum filter was used to optimise the visibility of the upper thoracic vertebrae.

Table 3.2

Correlations (Pearson's r) between the FEG angle and the three Cobb angles

	inner-Cobb Angle	mid-Cobb Angle	outer-Cobb Angle
Upright Standing			
FEG Angle	0.538*	0.814**	0.809**
P value	0.047	0.001	0.001
Slumped Standing			
FEG Angle	0.682*	0.821**	0.876**
P value	0.014	0.001	0.000

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

FEG data was recorded as the X-rays were taken. Again, the middle 5 seconds of each recorded trace were sampled and averaged to calculate the "FEG angle" for subsequent comparison with the angles measured from the X-ray.

Cobb angles were measured from the lateral X-rays using the Oxford Cobbometer (Original Orthopaedics Ltd, Surrey, UK). This device has been shown to be superior to the conventional method and is commonly used in clinical practice [334]. The edge of the Oxford Cobbometer was first aligned with the superior endplate of the vertebra which lay under the most cranially-positioned FEG end block as marked by the ball bearing. It was zeroed in this position and then moved to the inferior endplate of the vertebra lying under the caudally-positioned FEG end block. The angular difference between the two vertebral endplates was the Cobb angle.

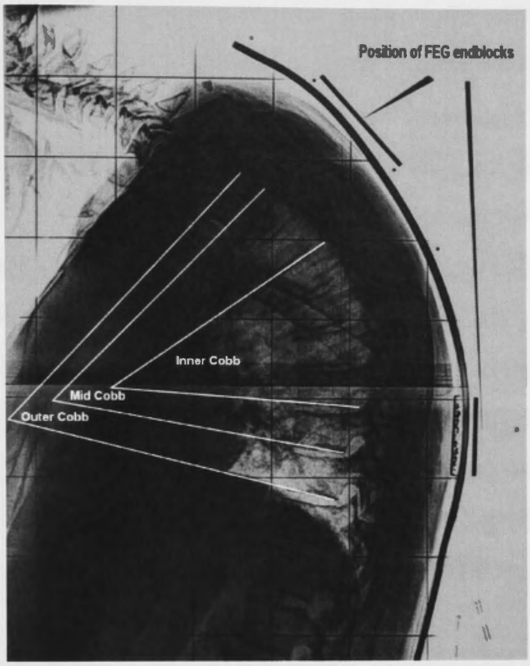


Figure 3.2 Lateral X-ray of a subject with a flexible electrogoniometer (FEG) attached to his back. The positions of the upper and lower end-blocks are indicated by braces. The end vertebrae used to measure the inner, mid and outer-Cobb angles were determined by their relation to the end-blocks. A flexicurve ruler is shown at the surface of the skin.

For the purposes of this experiment three Cobb angles were measured: those between the vertebrae underlying the inner margins of each end block ("inner-Cobb"), those between the mid-points of each end block ("mid-Cobb"), and those between the outer margins of each end block ("outer-Cobb") (Figure 3.2).

The three Cobb angles were then compared to the FEG angle for both erect and slumped standing positions using a Pearson correlation coefficient (below).

3.2.4. Data analysis

Summaries for continuous variables are reported using means ± standard deviations (or ranges).

Comparisons between sets of measurements were made using two different correlation techniques. Pearson's correlation coefficients were used to assess the strength of the linear relationship between the plurimeter and FEG measurements in experiment 1 and the three Cobb angles and the FEG angles in experiment 3. An intraclass correlation coefficient ($ICC_{2,1}$) of absolute agreement was used in experiment 2 as a measure of test-retest reliability of the FEG. A two way mixed model was used. The intraclass correlation coefficient ($ICC_{2,1}$) was used because we required a measure of homogeneity between two variables with shared metric and variance. In this situation an ICC is more appropriate than an interclass correlation coefficient such as the Pearson r [539]. All analyses were performed using SPSS version 16 (SPSS Inc. Chicago). Statistical significance was assessed at the 0.05 and 0.01 significance levels ($p<0.05$ and $p<0.01$).

3.3. Results

3.3.1. Experiment 1 – Bench test

The FEG angle and plurimeter angles between -10º and +60 º in both directions correlated very strongly ($r > 0.99$, $p < 0.0001$, Figure 3.3). Although there was excellent agreement between the plurimeter and FEG angles there were some differences in the absolute measured values which increased as the angle increased. At plurimeter zero, the FEG measured +0.12°. At +60° this difference increased to +1.5° (Figure 3.3).

3.3.2. Experiment 2 – Test-retest reliability

The mean test-retest reliability of all seven functional activities was $ICC_{2,1} = 0.92$ (range 0.89 to 0.95). Looking at the individual differences the $ICC_{2,1}$ was strongest for deep breathing and erect standing (0.95; $p < 0.0001$), followed by reaching for the ceiling (0.93; $p < 0.0001$), reaching for a line and touching toes (0.92; $p < 0.0001$), relaxed standing (0.90; $p < 0.0001$ and it was lowest for walking on the spot (0.89; $p < 0.0001$) (Figure 3.4).

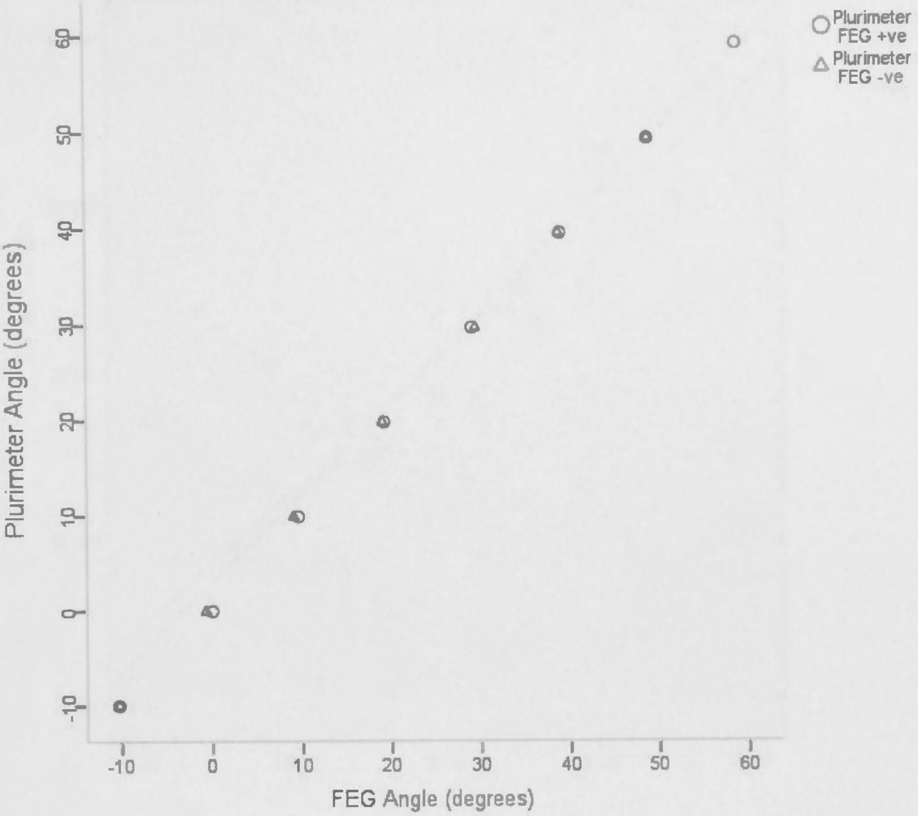


Figure 3.3 FEG angle compared to plurimeter angle measured in 10° increments from -10° to +60° flexion (+ve) and extension (-ve). The FEG and the plurimeter correlated nearly perfectly ($r > 0.99$, $p < 0.0001$).

3.3.3. Experiment 3 – Concurrent validity

The mean FEG angle for upright standing was 31° ± 7° compared to 39° ± 8° for slumped standing. The corresponding mean inner-Cobb angles were 24° ± 11° and 29° ± 10°, the mean mid-Cobb angles were 36° ± 12° and 41° ± 9°, and the mean outer-Cobb angles were 48° ± 13° and 52° ± 12°.

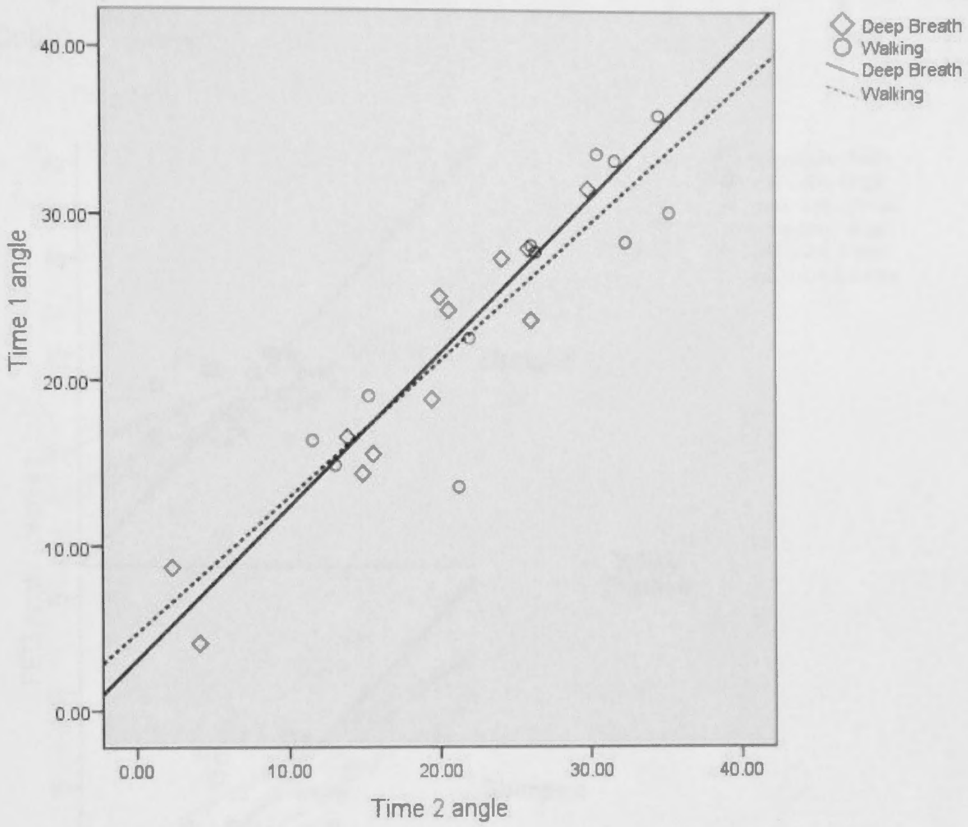


Figure 3.4 Test-retest reliability of the flexible electrogoniometer (FEG) angle measurements for the best and least correlated functional activities. Walking produced the lowest correlation ($ICC_{2,1} = 0.89$; $p < 0.0001$) and deep breathing (in standing) produced the highest correlation ($ICC_{2,1} = 0.95$; $p < 0.0001$).

Comparison of the FEG angles with the three Cobb angles for upright and slumped standing is shown in Figure 3.5. The mid-Cobb angle corresponded most closely to the line of identity (y=x) indicating that the mid-Cobb angle more closely approximated the FEG angle than the other two. This was supported by the fact that when the upright and slumped angles were collapsed, the mean mid-Cobb angle differed least from the FEG angle (Figure 3.6) with the mean differences being -8.4° ± 8.4° (inner-Cobb); 3.5°± 6.9° (mid-Cobb); and 14.9° ± 7.6° (outer-Cobb).

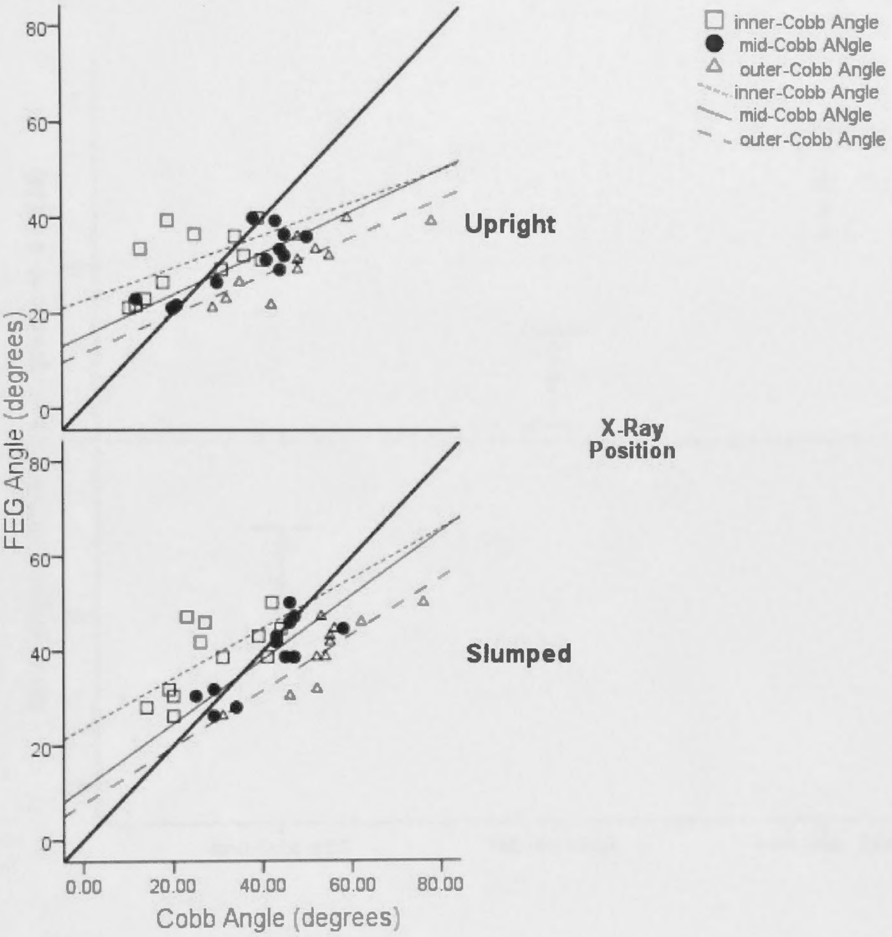


Figure 3.5 Flexible electrogoniometer (FEG) angles vs the corresponding inner-Cobb, mid-Cobb and outer-Cobb angles in upright and slumped standing. The thick black line represents the line of identity (y=x). The mid-Cobb points (solid circles) showed the closest association with the line of identity indicating that the FEG angle corresponds best with the mid-Cobb angle.

Correlation of the FEG and Cobb angles in the upright and slumped positions was performed separately (Table 3.2). Although all of the Cobb angles were significantly correlated with the FEG angle, the mid-Cobb and outer-Cobb were most highly correlated. Taking into account both the significant correlation and the absolute measured values, the FEG angle corresponded most closely with the mid-Cobb angle.

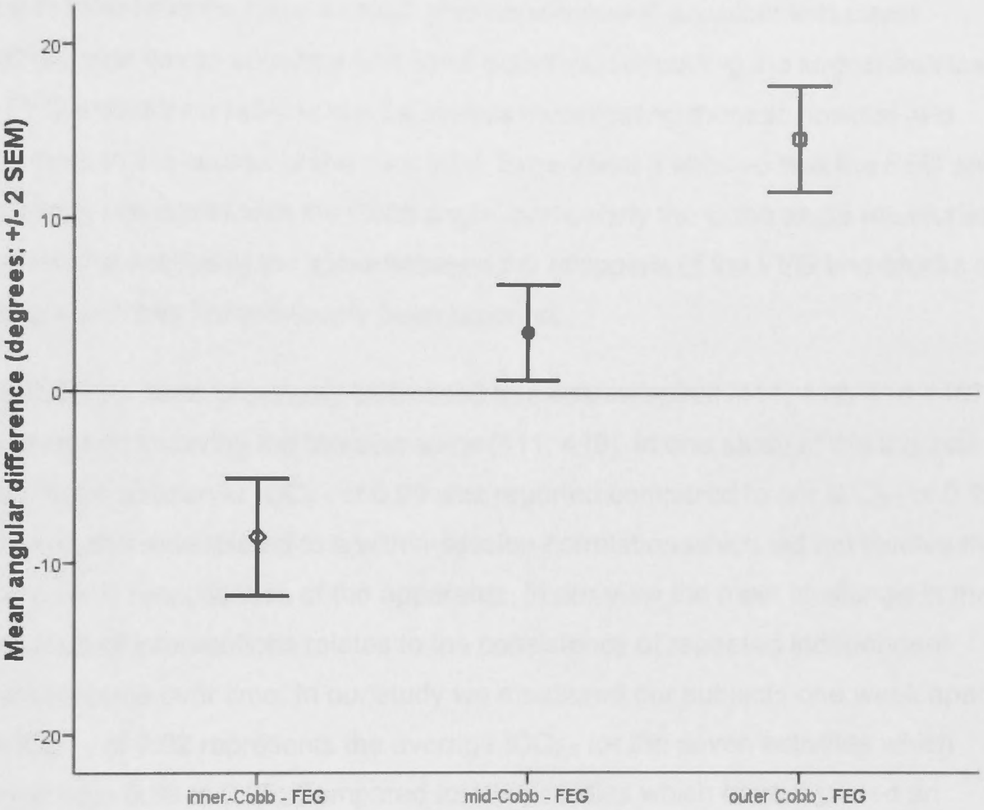


Figure 3.6 The mean absolute angular differences (± 2 SEM) between the FEG angle and the corresponding inner-Cobb, mid-Cobb and outer-Cobb angles. The mid-Cobb angular difference is the closest to the zero reference line indicating that it is least different from the FEG.

Bland-Altman Plots were constructed to confirm the results. These are included in appendix E.

3.4. Discussion

The aim of this study was to examine the accuracy, test-retest reliability, and concurrent validity of the FEG when measuring sagittal thoracic spine angle. We also aimed to discover which part of the FEG end-blocks correlated most closely with the Cobb angle being measured from the underlying vertebrae. In terms of accuracy, the FEG angle was shown in experiment 1 to be highly correlated with the plurimeter angle between -10° and +60°, a range appropriate to in vivo thoracic spine measurements. Experiment 2 also demonstrated excellent test-retest reliability over seven separate functional activities, supporting the suggestion that the FEG would be a reliable tool for studies investigating thoracic position and movement in the sagittal plane over time. Experiment 3 showed that the FEG angle was highly correlated with the Cobb angle, particularly the Cobb angle measured between the section of the spine between the midpoints of the FEG end-blocks a finding which has not previously been reported.

The FEG has been previously been used to measure spinal [411, 412, 416-418] including two involving the thoracic spine [411, 418]. In one study of the thoracic spine an intraobserver $ICC_{2,1}$ of 0.99 was reported compared to our $ICC_{2,1}$ of 0.92. However, this was related to a within-session correlation which did not involve the removal and reapplication of the apparatus. In our view the main challenge in the evaluation of interventions relates to the consistency of repeated independent measurements over time. In our study we measured our subjects one week apart. The $ICC_{2,1}$ of 0.92 represents the average $ICC_{2,1}$ for the seven activities which ranged from 0.89 to 0.95. Compared to other studies which have reported an $ICC_{2,1}$ of between 0.64 and 0.72 for standing photographic measures [345], our results are excellent.

In the past the Cobb angle has been directly compared to other non-invasive devices such as the flexicurve [333], the kyphometer [37, 333], the arcometer [414] and a stereovideographic technique [343]. In all cases there is a discrepancy between the Cobb angle and the angle measured by the device at the skin surface. In our study, the mean difference between the FEG angle and the mid-Cobb angle was 3.5° ± 6.9°, the mid-Cobb angle being larger than the FEG angle. In other studies with different skin-based instruments, the absolute differences ranged between 2.9° and 9° with reported standard deviations as high as 8.8° [37, 343, 414]. The difference, therefore, between radiographic and skin-based measurements is a consistent finding. The discrepancy could be due to a number of factors including the intrinsic error associated with the Cobb measurement technique [332] and the distortion in the shape of the curve by intervening soft tissues particularly the dorsocervical fat pad (which can be as deep as 8 cm over the upper thoracic spine [540], although for the most part the FEG was positioned below it.

Of the other studies which have compared the Cobb angle with a skin-based measurement tool, the highest correlation was reported by Leroux et al. [343]. Their stereovideographic technique yielded an $ICC_{2,1}$ of 0.94 compared to our correlation of $r=0.8$. Their superior correlation may be explained by the fact that their cohort had a mean age of 13.5 years and so a) the vertebrae were less likely to be wedged, reducing the likelihood of overestimation of the Cobb angle [233], and b) there was likely to be less distortion of the curve by overlying soft tissues. The use of an $ICC_{2,1}$ to compare methods with potentially different variance is another posible explanation for the difference [539]. Another study compared the Debrunner kyphometer, another skin-based measure, with the Cobb angle in young subjects with increased kyphosis and demonstrated a correlation of $r=0.76$ [37]. This level of correlation is similar to ours.

This study has a number of limitations. First, the number of subjects was small. The concurrent validity study (experiment 3) involved radiation exposure and therefore we were ethically bound to keep our numbers to a minimum since we were exposing our subjects to a risk without expectation of benefit. The numbers for the test-retest study (experiment 2) were also small but the correlations were sufficiently strong that it was deemed unnecessary to increase the sample size.

The error which is inherent in the Cobb angle method has been widely discussed and its status as the 'gold standard' has frequently been questioned [26, 35, 332]. So our use of the Cobb angle as the common reference measure for concurrent validity could also be questioned. However, in spite of the fact that other methods using lateral X-rays have been proposed as more accurate and reliable methods of characterizing the kyphotic curve [26, 39] the Cobb method remains the clinical standard and so is still more meaningful to the majority of clinicians. Accordingly we felt it most appropriate to work with the Cobb as our reference measure. As other techniques become more widely used clinically, they may become increasingly accepted as legitimate reference measures.

Interobserver reliability was not addressed in this study because we were primarily interested in validating the FEG for the measurement of thoracic kyphosis before and after an intervention which would not require multiple measurers. Test-retest reliability was therefore more appropriate.

The FEG manufacturers report an accuracy within ±1° [413] but when we bench-tested between -10° and +60° we found that the FEG lost accuracy in the outer ranges (1.5° discrepancy at +60°). The absolute angular extent of thoracic kyphosis is variously reported, the size of the angle being dependent on the number of vertebrae being measured, but most authors report angles of less than 60° [20, 21, 34-36]. In our study none of the sagittal spine angles measured by the FEG exceeded 51° so the slight loss of accuracy at extremes of range was unlikely to affect our results.

Although the FEG is a dynamic measurement device, the subjects in experiment 3 (concurrent validity) were measured in static positions (erect and slumped standing) because the Cobb method, with which the FEG was being compared, is a static measurement. Arguably we could have compared the FEG to a dynamic measurement device for this study but, as above, we chose the Cobb method because of its status as the ‘clinical gold standard’ tool for measuring thoracic kyphosis.

3.5. Conclusion

In summary, this study set out to investigate the validity of the FEG as a tool for measuring sagittal thoracic angle in interventional studies of thoracic kyphosis. We have demonstrated that the FEG is accurate, has excellent test-retest reliability, and has concurrent validity when compared with the Cobb angle (currently the clinical gold standard measurement). We have also shown that the FEG angle correlates and agrees best with the Cobb angle when it is measured between the vertebrae underlying the mid-points of the FEG end-blocks. This is an important finding for future spinal applications. The FEG is therefore proposed as an ideal tool for the evaluation of interventions aimed at improving thoracic spine posture.

Because this study showed that the FEG was a valid instrument for the thoracic spine, the method described in this chapter was used for the randomised controlled trial described in chapter 9.

Chapter 4.

Management of Thoracic Hyperkyphosis: A Survey of Australian Physiotherapists

4.1. Introduction

Thoracic hyperkyphosis has been discussed in detail in chapter 2. Briefly therefore it is defined as an antero-posterior curvature of the thoracic spine of greater than 40º[20]. It is a common feature of aging [19], with the reported prevalence being up to 50% in males and 65% in females over the age of 65 [30]. This age-related increase in curvature is accompanied by a loss of range of movement and increased stiffness[44] and is of particular importance to the physiotherapist because it is associated with pain and dysfunction of both spine and shoulder [68, 87], falls in the elderly [63], respiratory compromise [62], increase in the risk of osteoporotic fracture [13], and increased mortality rates in the elderly [64].

Various treatments for hyperkyphosis have been proposed and some have been assessed with regard to efficacy but with unclear results. These have been described in detail in chapter 2 (0) so a very brief summary is presented here. A pilates programme reduced kyphosis in one study [100] but not another [452]. Taping was shown to significantly reduce kyphosis while the tape was in place but it was unclear whether this effect persisted after removal of the tape [366]. Yoga reduced kyphosis if measured by a flexicurve, but not when measured by a kyphometer [9]. Prone extension exercises were apparently ineffective with a study of older women showing no tangible decrease in thoracic kyphosis after two years of extension exercises when compared to a control group [10]. To date, there have been only two studies which have reported a sustained decrease in kyphotic curvature: one involved multiple extension exercises [98], and the other involved a combination of postural re-education, motivational interviewing, a stretching program and progressive resisted strengthening [8]. Unfortunately neither trial was randomised or controlled.

Well designed randomised controlled trials (RCTs) are clearly needed to determine the effectiveness of the various interventions aimed at reducing kyphosis. In order to guide the design of such a trial it is important to ascertain which treatments are currently being used by physiotherapists. There has not yet been such a survey published anywhere in the world.

Accordingly, the aim of this survey was to determine the current practice of Australian physiotherapists regarding the assessment and treatment of thoracic hyperkyphosis. A further aim was to determine how frequently the condition was encountered in routine practice and also how many treatment sessions were typically assigned by physiotherapists to addressing the problem.

4.2. Methods

4.2.1. Study design

The study was an observational, stratified cross sectional mailed survey. Ethics approval was granted by the ACT Health Human Research Ethics Committee and by the Australian National University Human Research Ethics Committee.

4.2.2. The questionnaire

The questionnaire consisted of six questions. The number of questions was kept to a minimum in order to maximize the response rate [541]. Questions 1 to 4 and question 6 were multiple-choice format with an additional facility for free text, but question 5 was free text only. The six questions and their response options are shown in Table 4.1.

Table 4.1

The questions and response options contained in the questionnaire. Responses were multiple choice and free text.

1. **Which of the following would best describe your patient profile?**

   Mostly musculoskeletal, mostly neurological, mostly respiratory, equally mixed patient profile, other.

2. **How often do you encounter increased thoracic kyphosis in your patient population over 40 years of age?**

   Every day, once a week, once a month, once a year, never* (*Please specify whether you do not see kyphosis OR do not see people over 40)

3. **How do you identify and/or measure thoracic kyphosis?** (tick any or all that apply). Visual inspection, X-ray (Cobb angle) inclinometer, plurimeter, photography, flexicurve, electrogoniometry, tragus to wall measurement, other

4. **On average, how many times would you treat someone for thoracic kyphosis?**

   Once only, twice only, three times, four times, five times, more than this (please specify).

5. **What strategies do you use to treat patients who have poor thoracic posture, whether it is related or unrelated to their presenting problem?** (free text)

6. **On what basis do you make your decisions about how to assess and treat people with increased thoracic kyphosis?** (tick any or all that apply).

   Undergraduate training, recent professional development, own reading of the literature, personally-conducted clinical research in this area, other

4.2.3. Questionnaire development

The questions were formulated in order to inform a larger trial of treatment for hyperkyphosis being undertaken by the authors. A draft survey was sent to eight experienced, but non-practicing, physiotherapists with a request to complete and comment. The comments and mode of completion led us to make question five free text (Table 4.1). The free text option was chosen because a true representation of what physiotherapists were doing in clinical practice was sought. The pilot study suggested that the inclusion of a list of treatment options might result in respondents selecting the options which they believed they 'should' be using rather than those that they actually did use. This phenomenon has been previously described as bias resulting from the 'pursuit of prestige' [542].

4.2.4. Sampling design

A questionnaire survey was distributed to clinical physiotherapists working in Australian clinics and hospitals. The sample was stratified by geographical area (i.e. State or Territory) and place of work (clinical group) i.e. hospital, community health centre (CHC), or private practice (PP), generating 24 geographical and clinical groups (GCGs). Stratification enabled us to survey similar numbers of physiotherapists in each state thereby not biasing the sample to the larger regions and cities. The stratification also allowed for the inclusion of similar numbers of PP, hospital and CHC physiotherapists who might otherwise have been under-represented. In this way it was hoped that a more representative sample would be achieved, avoiding the inevitable bias to larger centres and groups inherent in un-stratified designs.

Physiotherapy clinics and hospitals were identified by searching State Health Department websites. In addition, private practitioners' names were identified by searching the telephone directory. This strategy was employed to avoid biasing the sample by the use of selective lists requiring membership (eg. the Australian Physiotherapy Association); and the potential for a high percentage of incorrect contact details in registration board lists [543]. Twenty-one physiotherapists in each GCG were selected (using random number tables) to receive questionnaires. In some smaller areas (i.e. the Australian Capital Territory, the Northern Territory, and Tasmania) there were too few eligible physiotherapists in some clinical groups to send the full quota of 21 questionnaires. In these cases the maximum number possible was dispatched.

Each questionnaire was labelled with the target state and practice type but not the name of the therapist or clinical site. This strategy ensured anonymity while permitting identification of the respondent's GCG. Anonymity was an important consideration in order to ensure that respondents felt able to respond honestly without fear of being judged.

4.2.5. Data analysis

The responses were examined as a function of practice group, clinical profile group and geographical group using a chi-squared test for categorical data and two sample t-tests for continuous data. Where chi-squared analysis was not possible because of low cell frequency, a Fisher's exact test was used. A Pearson's correlation coefficient was used to examine the agreement between two assessors of a random sample of responses to question 5. The significance threshold was set at $p<0.05$.

4.3. Results

In total 468 questionnaires were sent out. Of these, 228 (49%) were returned. Of these eight were void leaving 220 for analysis (Table 4.2). The proportions of respondents from the various geographical areas are shown in Figure 4.1. A few of the respondents offered comments and a summary of these can be found in appendix A1.

Two experienced physiotherapists (JS and DP) classified the free text answers in question five from 15 respondents selected at random. This was done to assess the level of agreement for the classification strategy. The correlation was excellent ($r = 0.88$; $p<0.0001$).

Table 4.2

Proportion of respondents by geographical area and clinical site.

	HOSP response/sample	% returned	CHC response/sample	% returned	PP response/sample	% returned	Total % returned
NSW	16/21	76%	7/21	33%	10/21	48%	52%
ACT	13/20	65%	2/10	20%	16/21	76%	64%
NT	3/20	15%	5/8	63%	10/21	48%	42%
SA	9/21	43%	9/21	43%	4/21	19%	35%
VIC	14/21	67%	13/21	62%	16/21	76%	68%
WA	12/21	57%	4/21	19%	10/21	48%	41%
QLD	12/21	57%	9/21	43%	11/21	52%	51%
TAS	5/20	25%	5/12	42%	13/21	62%	43%
Total	84/165	51%	54/135	40%	90/168	54%	49%

4.3.1. Question 1 - Patient profile

Of the 220 respondents, three quarters reported that they saw mainly musculoskeletal patients. Of the remainder, most had a mixed patient profile, a few saw primarily neurological or respiratory conditions and 6% fell into the 'other' group which included women's health, hand therapy or 'unspecified'. There were no non-responders (Figure 4.1).

4.3.2. Question 2 - Prevalence of thoracic hyperkyphosis in the clinic population

Four respondents did not answer this question. Regardless of clinical group over 70% of respondents reported seeing patients with hyperkyphosis at least once a week, and 40% of respondents from CHCs and PPs saw such patients daily Table 4.3. There was no significant difference between the three clinical groups.

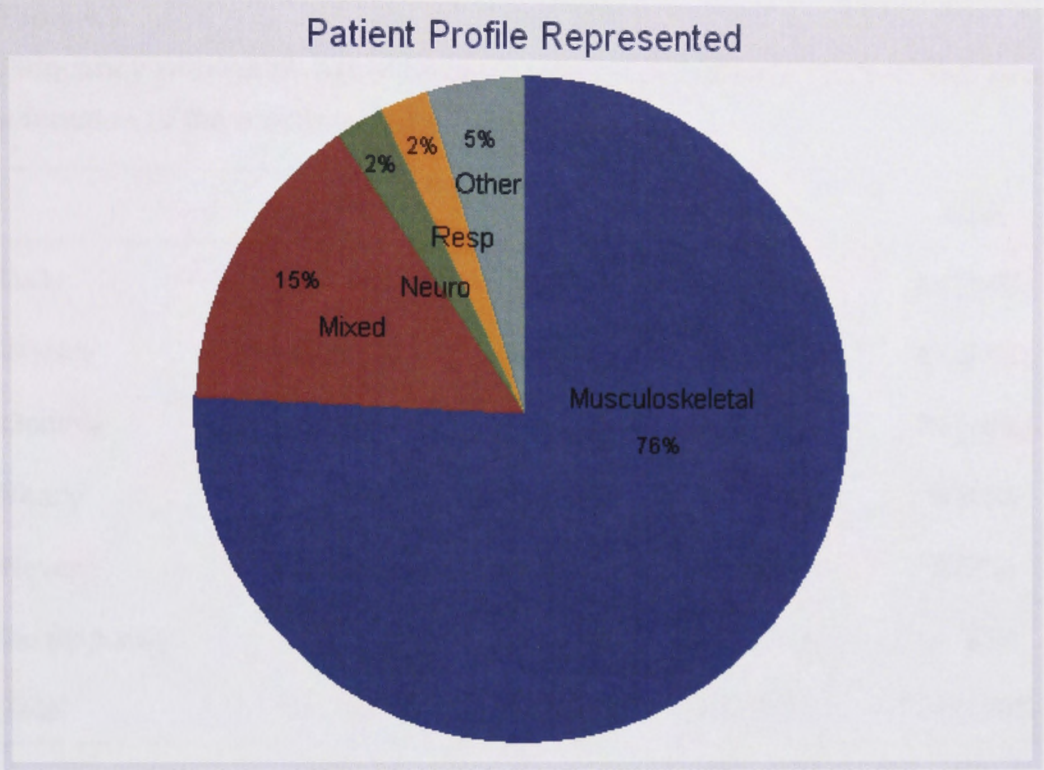


Figure 4.1 Clinical profile of the study respondents.

Note. 'Neuro' = neurology, Resp = respiratory, Mixed = mixed clinical practice.

4.3.3. Question 3 – Identification and measurement of kyphosis

Five respondents did not answer this question. The vast majority (98%) of those that did reported using visual inspection to measure the degree of kyphosis and, of these, 66% used it exclusively. The next most common tool was lateral X-ray (21%). The other measurement modalities used are shown in Figure 4.2. A significantly larger proportion of CHC physiotherapists (33%) used X-ray to evaluate kyphosis than either PP (19%) or hospital (14%) (Fishers exact test, p=0.03).

Table 4.3

Frequency with which hyperkyphosis was encountered in clinical practice as a function of the different clinical groups.

	CHC	PP	Hosp	Total
Daily	23 (45%)	35 (41%)	28 (34%)	86 (39%)
Weekly	17 (33%)	34 (40%)	31 (37%)	82 (37%)
Monthly	6 (10%)	11 (13%)	18 (22%)	35 (16%)
Yearly	3 (6%)	0 (0%)	5 (6%)	8 (4%)
Never	2 (4%)	3 (4%)	0 (0%)	5 (2%)
No response	1 (2%)	2 (2%)	1 (1%)	4 (2%)
Total	52 (100%)	85 (100%)	83 (100%)	220 (100%)

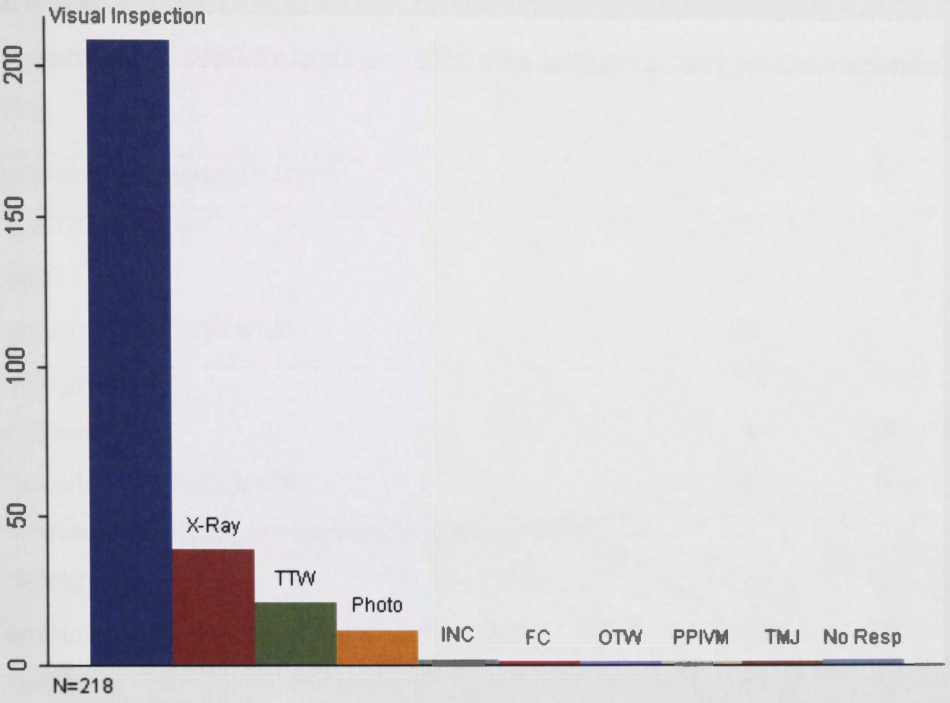


Figure 4.2 Measurement modalities used to assess and monitor kyphotic angle.

X-Ray = Cobb angle from X-ray, TTW = Tragus To Wall distance, Photo = Photography, INC = Inclinometer, FC = Flexicurve, OTW = Occiput To Wall distance, PPIVM = Passive Physiological Intervertebral Movement, TMJ = Temporomandibular joint to wall measurement, No Resp = No Response.

Table 4.4

The number of respondents (n=220) who selected the various assessment tools

Kyphosis assessment tools	A	B	C
Visual Inspection	210	141	210
X-ray	45	2	43
Tragus- to-wall distance	24	1	23
Photography	15	1	14
Inclinometry	3	0	3
Occiput-to-wall distance	2	0	2
Passive Physiological Intervertebral Movements (PPIVM)	1	0	1
Temperomandibular joint–to-wall distance	1	1	0
Flexicurve	1	0	1
Plurimeter	0	0	0
Electrogoniometry	0	0	0
No Response	5	0	0

Note. Column A indicates all of the respondents who selected that tool; column B, those where the tool in column A was the only one selected; and column C, those who selected the selected tool in conjunction with visual inspection. All of the respondents who used more than one tool used visual inspection.

4.3.4. Question 4 – Treatment frequency

Fifty respondents did not answer this question. Of those that did the estimated number of sessions ranged between 0 and 9 with 35% opting for 3 sessions and 22% for 4 (Figure 4.3). As a function of patient profile type (question 1), musculoskeletal physiotherapists reported that they would allocate significantly more treatment sessions to thoracic hyperkyphosis than would all other groups (3.6 ± 1.4 vs 2.0 ± 1.8 two sample t-test, $p<0.0001$). 46% of the respondents who commented (appendix A1) indicated that hyperkyphosis was never the presenting problem making estimation of the number of treatments too difficult.

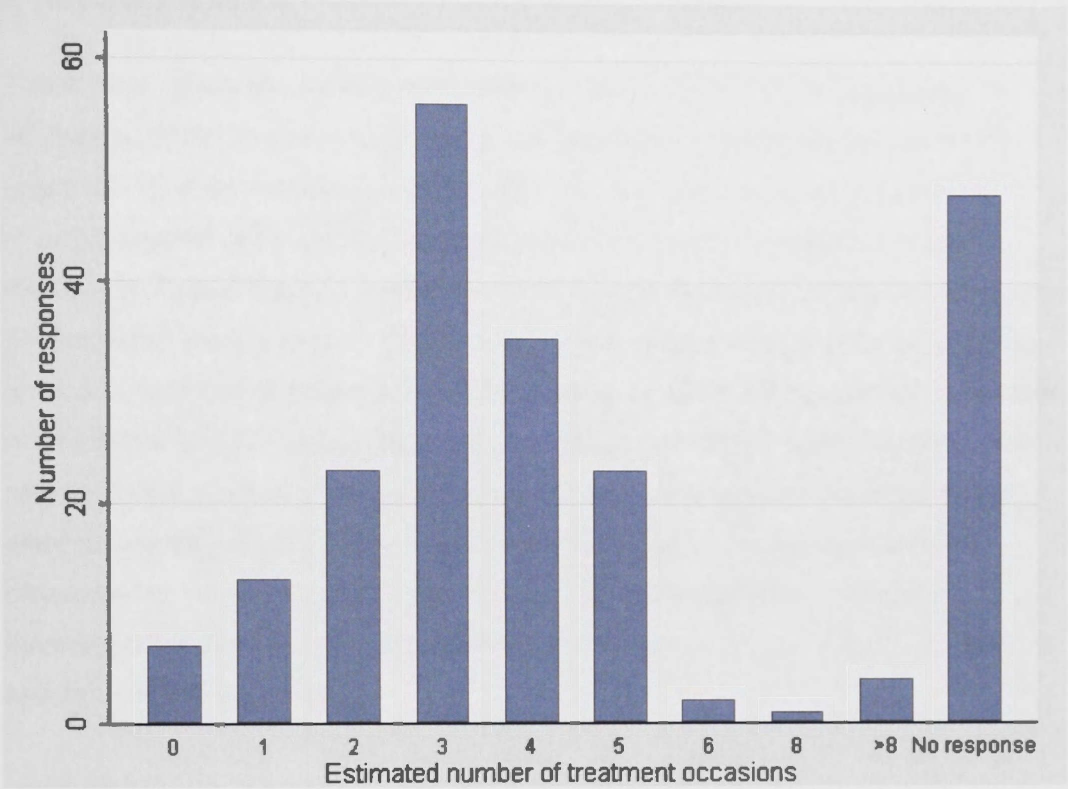


Figure 4.3 Estimated number of treatment sessions allocated by the respondents required to reduce the kyphotic angle and improve posture.

4.3.5. Question 5 - Treatment strategies

Eleven respondents chose not to answer this question. In total, the respondents listed 32 separate strategies, each respondent listing an average of 4 different strategies. The responses were collapsed into 8 categories as shown in Figure 4.4. The first six of these categories were considered to be actively targeting hyperkyphosis while strategies such as acupuncture, electrotherapy, breathing exercises and general exercise were allocated to the 'other' group because they were aimed at treating the secondary effects of hyperkyphosis. The majority of those who responded selected postural re-education (90%) followed by stretch

(71%), strength (64%) and joint mobilization (53%). A summary of all of the results is shown in Figure 4.4.

There were no significant differences between any of the GCGs for postural re-education, stretching or strengthening, nor was there an effect by patient profile (question 1). Joint mobilization and soft tissue mobilization were only used by musculoskeletal or mixed clinical profile respondents and significantly more musculoskeletal physiotherapists used joint mobilization compared to mixed profile physiotherapists ($p < 0.001$). There was a significant difference between practice groups in their use of braces ($p=0.007$): hospital physiotherapists did not use them at all while 9% of PP physiotherapists and 6% of CHC physiotherapists did. With respect to the number of strategies used to treat thoracic hyperkyphosis, there were no significant differences between practice groups but musculoskeletal physiotherapists used significantly more treatment modalities for thoracic hyperkyphosis than those in other patient profile groups (mean 4.2 ± 1.8 vs 3.3 ± 2.3; two sample t-test, $p=0.002$).

4.3.6. Question 6 – Evidence supporting treatment decisions.

Eleven of respondents did not answer this question. Of the remainder, 69% reported using knowledge gained from their undergraduate education, 42% cited recent professional development opportunities (RPD), 34% had read relevant material, 20% reported using clinical experience, 4% of the respondents had done research in the area and 4% utilized knowledge from postgraduate education. There were no significant differences between GCGs.

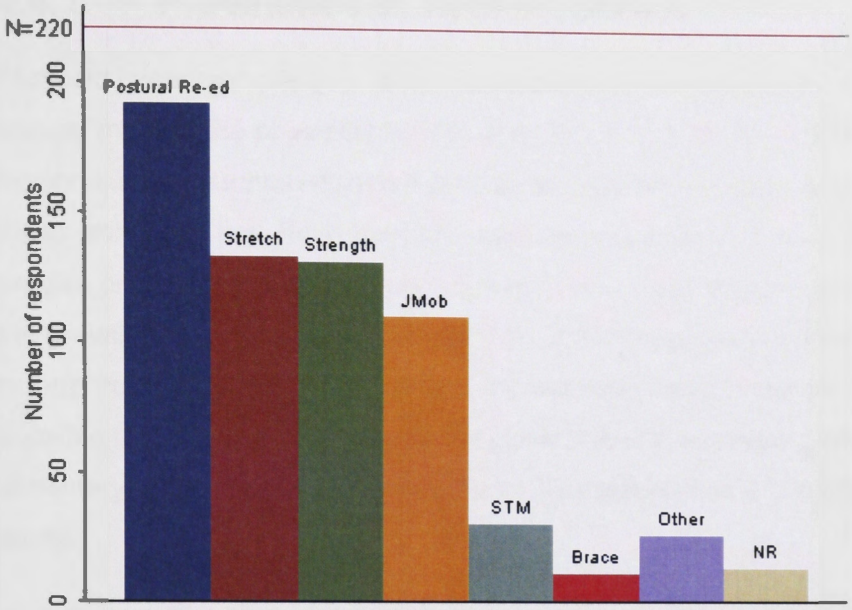


Figure 4.4 Treatment strategies identified by the respondents collapsed into eight categories.

4.4. Discussion

Age-related increased thoracic hyperkyphosis is a well recognised but understudied condition [329]. This study aimed to investigate how physiotherapists in Australia assess and manage thoracic hyperkyphosis. This is the first time this subject has been investigated. The principal findings were: first, that thoracic hyperkyphosis is encountered by most physiotherapists on a daily or weekly basis but that it is often not the main complaint; second, most physiotherapists assess kyphosis using only visual inspection; third, the most widely used treatment modality was postural re-education and the majority of respondents estimated that they would allocate an average of 3 treatment sessions to ameliorate the problem; finally, the most commonly selected evidence on which physiotherapists based their treatment decisions in this area was their undergraduate education. A number of respondents commented that they felt under-informed about the effective management of hyperkyphosis.

4.4.1. Prevalence of hyperkyphosis

Thoracic hyperkyphosis is a common condition in the elderly and should arguably occupy more of the physiotherapist's attention. In this study over 70% of all respondents encountered hyperkyphosis at least once a week and over 40% of those working in hospitals or private practice encountered it daily. Although the precise prevalence of hyperkyphosis is not known, published data indicates that the prevalence may be as high as 50% to 65% in people over 65 without osteoporosis.[30]. If hyperkyphosis is increased in more sedentary people, it is possible that this prevalence may rise given the ever-increasing computer use and sedentary occupation in western society. This is therefore a condition worth future study.

4.4.2. Assessment of kyphosis

Ninety eight percent of the respondents in this study assessed kyphosis by visual inspection and for 66% it was the sole assessment tool. Even under the most controlled conditions and with the assistance of photography, visual inspection has been shown to demonstrate substantial intra-observer variability [337, 345, 544] which makes it an inappropriate assessment tool. The 'clinical standard' method of measuring kyphosis is the 'Cobb angle' which is derived from lateral X-ray [25] and this was used by 21% of the respondents. The Cobb angle is relatively reliable but the multiple measurements needed for the evaluation of treatment efficacy would result in significant radiation exposure rendering it impractical. The increased use of X-ray amongst CHC physiotherapists may relate to easier access to radiology. Tragus-to-wall and occiput-to-wall measurements are both used to measure kyphosis, especially in patients with ankylosing spondylitis [545-547]. They have been shown to be equally reliable with repeated measure ICCs of greater than 0.93 [546] but they actually measure head forward posture, not thoracic kyphosis [337, 368]. Photographs can be a useful record but reliability relies on highly controlled conditions and the use of skin markers [343, 344] which does not correlate with the clinical situation. Inclinometry has been used by a number of researchers [3, 366, 548] but it is only accurate to within 10% of the measured spinal angle [7].

Conversely the flexicurve provides an accessible, objective measure which is suitable for use in physiotherapy practice. It is an inexpensive and relatively reliable tool with repeated measure ICCs of 0.88 and higher [333, 335, 337, 549]. However, it is rarely used. This survey showed that only 1% of the respondents used the flexicurve implying that clinicians are either unaware of the instrument or find the method too time-consuming. Other reliable instruments such as the kyphometer [339] and the spinal mouse [46] were not included in the list of options on the questionnaire and were not identified by any of the respondents. In summary, the majority of physiotherapists appear to be using unvalidated tools. Education is clearly required in this area.

4.4.3. Treatment strategies

Between them, the physiotherapists who participated in this study reported using a total of 32 different treatment strategies to manage thoracic hyperkyphosis, but in reality there is no strong evidence for any of them. The most frequently utilized category was postural re-education followed by stretching and strengthening. Although specific postural training with recruitment of deep postural muscles has been shown to be effective in the neck and lumbar regions [550-552], the effectiveness in thoracic region has not been convincingly demonstrated. Only two studies have demonstrated a significant improvement in kyphotic angle after a therapeutic exercise programme [8, 98]. The first was a multimodal intervention study which generated a 6 degree change, sustained after one year [8, 507], and the second used multiple extension exercises [98]. Neither trial was randomised or controlled thereby limiting their value in terms of clinical evidence [553].

Joint mobilization for thoracic hyperkyphosis has not been critically assessed. Nevertheless it was used by 50% of the respondents particularly those with musculoskeletal or mixed patient profiles. Joint mobilization can ameliorate pain [554], but there is no evidence to support it as a technique for reducing kyphosis *per se*. Similarly, although 14% of the respondents reported using soft tissue massage, there is no published evidence to support its efficacy. Like joint mobilization, only respondents with either musculoskeletal or mixed patient profiles reported using it suggesting that the selection of these two modalities may be based more on familiarity than knowledge of their effectiveness.

A few respondents used braces. There is some evidence that braces may be effective for reducing kyphosis after vertebral fracture [555] and, (somewhat counter-intuitively), one study reported increased back strength after wearing a particular brace [556]. However the use of bracing in the non-traumatic situation has not been studied. Of note, hospital physiotherapists used braces less frequently than the other groups, perhaps because of resource limitations.

The number of treatments needed to effect a change in posture is unknown. About a quarter of respondents in this study nominated three sessions but a similar number chose not to answer the question at all. On the basis of accompanying comment, the high non-response rate appears to be due to the fact that many of the respondents felt unable to separate the treatment for the hyperkyphosis from other treatment modalities which were specifically aimed at the presenting problem. In reality, three treatment sessions is a very small number to offer to treat a problem which develops over a lifetime, intervention studies have typically used treatment durations of between 12 weeks and 2 years to evaluate the effectiveness of a strategy for thoracic hyperkyphosis [8, 9, 36, 98, 452]. Interestingly musculoskeletal physiotherapists, who conceivably might have more skill and experience in the area, allocated significantly more sessions than the other patient profile groups. In summary, this study has demonstrated a need for studies to determine the optimum method and duration of treatment for reducing thoracic hyperkyphosis.

4.4.4. Evidence base

As above, evidence regarding the best method of reducing thoracic hyperkyphosis is very limited [19]. In this study the majority of respondents indicated that they relied on their undergraduate education to inform their practice. For many, if not all, the education they received as an undergraduate could not have been evidence-based since there is so little evidence available. This is reflected in accompanying comments which clearly reflect a need for more information in this area.

4.4.5. Limitations of the study

The main limitation of this study was that the response rate was relatively low (49%), especially for question 4 which was only 36%. However, our overall response rate was comparable with other surveys of the target group [557-559]. The low response rate was probably primarily due to the fact that the questionnaire was anonymous since anonymity has been reported to reduce rates by up to 16% and reminder mailings can increase response rates by 16% [560]. We chose, perhaps naively, not to do this in order that the respondents who had completed and returned the forms were not inconvenienced further and also for future researchers who would potentially be negatively impacted by 'respondent fatigue'. The issue of what constitutes acceptable response rates has been hotly debated [560-562] fuelled by the trend towards reduced respondent numbers in recent times [561, 562]. Response rates can be low as long as the respondents are representative of the group as a whole and there is no suspicion of bias [560, 561]. In this survey the stratified design protected us against potential bias by ensuring that smaller geographical and practice areas were well represented. Further evidence that the response group was not biased lies in the fact that 75% of the sample had a musculoskeletal profile, which agrees with the proportions of clinical physiotherapists reported in larger surveys of this population [563]. Another potential limitation of this study may be that the questionnaire only included six questions and the information gleaned was therefore relatively basic. Ideally the results would have benefited from a better understanding of the clinical reasoning behind the choices made but we intentionally kept the questionnaire short to maximize the response rate. By making the format of question 5 free-text errors associated with 'pursuit of prestige' by the respondents were eliminated [542] but it meant that responses had to be categorized *post hoc*. Thus the results could potentially reflect the opinion of the authors with respect to which categories the responses were allocated. To avoid this criticism, the raw data have been presented in appendix A2.

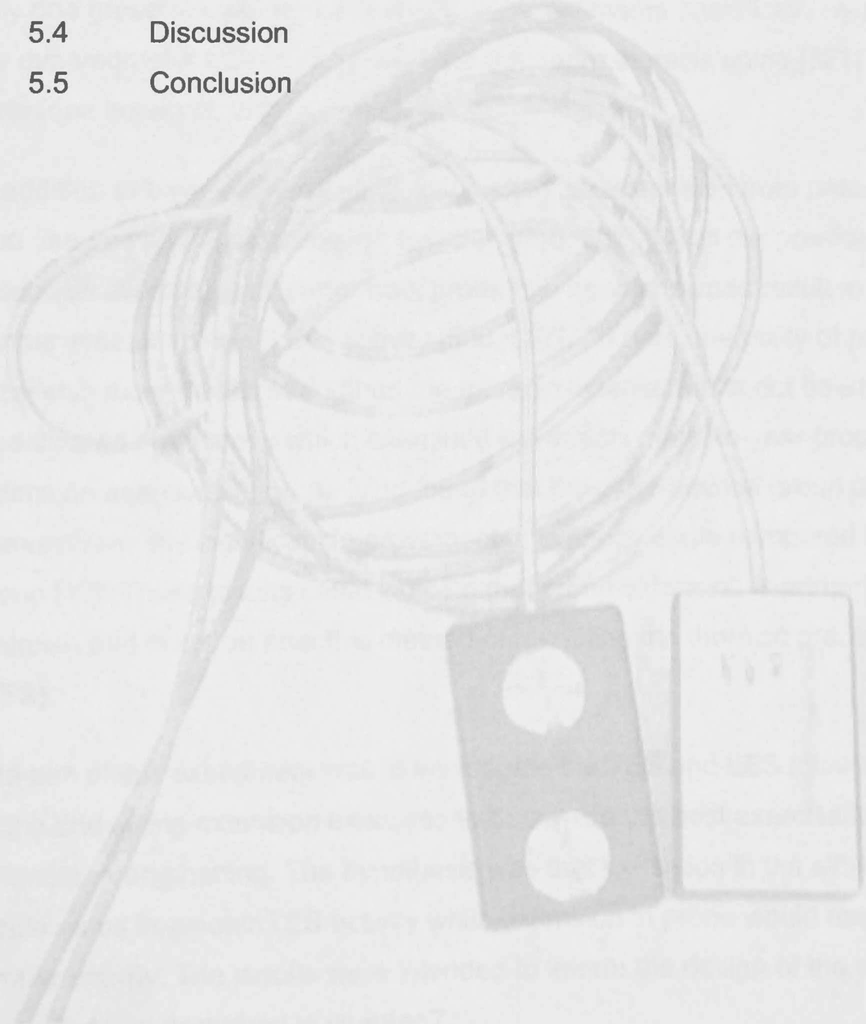
4.5. Conclusions

In conclusion, this study, which set out to investigate how physiotherapists in Australia assess and manage thoracic hyperkyphosis has shown that the problem of hyperkyphosis is highly prevalent with most physiotherapists encountering it at least weekly. In spite of considerable evidence against its use, most respondents still used visual inspection as their only evaluation tool. The respondents in this study identified 32 separate treatment modalities which they used to treat hyperkyphosis. The most common group of treatments was postural re-education followed by stretching and strengthening. Joint and soft tissue mobilizations were only used by musculoskeletal physiotherapists. Finally the majority of respondents relied on their undergraduate education to inform their practice with respect to thoracic hyperkyphosis, a number of respondents commenting that they felt under-informed in the area.

Identification and treatment of postural abnormalities is of key importance to physiotherapists and yet there is still a dearth of evidence related to the effective treatment of thoracic hyperkyphosis [19]. The results of this study have informed the design of the randomised controlled trial which is described in chapter 9.

Chapter 5.

The Electromyography (EMG) Pilot Study



5.1. Introduction

Increased back extensor strength has been reported to protect against hyperkyphosis by reducing the degree of age-related change and decreasing the incidence of thoracic wedge deformity [480]. Accordingly back extensor strengthening is recommended for the treatment of hyperkyphosis [564, 565] and many clinicians use strengthening as part of their treatment approach (see chapter 4). Thoracic extension exercises and back extensor strength testing are commonly performed in prone lying (2.7.1). However, the prone lying position can be difficult for both the elderly and the disabled to assume [283]. The sitting position has been used by a small number of investigators to measure back extensor strength but only one group sought to isolate the thoracic extensors specifically by positioning the dynamometer transducer head over the upper thoracic spine [321]. Their technique however, was not validated.

In addition to being a thoracic extension exercise, extension from prone lying is also used as a lumbar extension exercise [566, 567]. Of all the positions in which extension exercises are performed, prone has been shown to result in the greatest lumbar erector spinae (LES) activity [566, 567]. To date, the utility of prone extension exercises to strengthen the thoracic extensors has not been specifically investigated but a study which examined the effects of a two-year programme of extension exercises in prone lying found that the experimental group did not demonstrate any significant improvement in kyphotic angle compared to the control group [10]. These results could indicate that prone extension is primarily a LES exercise and is not an effective method of recruiting the thoracic erector spinae (TES).

The aim of this experiment was to investigate the TES and LES muscles during prone and sitting extension exercises to determine the best exercise for thoracic extensor strengthening. The hypothesis was that extension in the sitting position would result in greater TES activity while extension in prone would result in more lumbar activity. The results were intended to inform the design of the randomised controlled trial described in chapter 7.

5.2. Method

5.2.1. Subjects

The subjects for this pilot study represented a sample of convenience drawn from hospital staff members. Exclusion criteria included a past history of thoracic or lumbar spine problems. No one was excluded. The sample comprised 11 subjects (6F, 5M) aged 46 ± 18 (mean ± SD).

5.2.2. EMG method

Two surface EMG (sEMG) SX230 preamplifiers with built-in dual electrodes (Biometrics Ltd, Cwmfelinfach, UK) were attached to the skin 2 cm lateral to the T3 spinous process and 2 cm lateral to the L4 spinous processes (Figure 5.1). The skin for each subject was prepared by washing the recording site with warm water as per the manufacturers instructions [568]. The L4 recording site has been widely used to record from the LES [425, 433].The T3 site however, has only recently been proposed [154]. It is suggested that this site represents a more appropriate recording site for the TES than the commonly-reported T9 site [218, 428, 435] because of the presence of an electrically silent window produced by the aponeurotic attachment of the trapezius and rhomboid muscles to the spine at this point [154]. The T9 site lies directly over the trapezius muscle belly and therefore the trapezius is most likely to be the muscle being recorded rather than the ES [154].

The preamplifiers were calibrated to zero prior to being attached to the subject. A ground strap (Biometrics R206) was attached to the subject so that the ground electrode contacted the styloid process over the right wrist. With the preamplifiers in place, the subjects were asked to extend maximally in prone with their arms above their heads (AUT, Figure 5.2), and hold this position for 5 seconds in order to establish the correct channel sensitivity for each of the muscles (0-3mV). The sampling rate for each recording was 1000 per second.

The rectified sEMG traces were averaged over 1 second. The values were normalised by expressing them as a fraction of the maximum value obtained from any of the extension tasks for each individual (2.7.2).

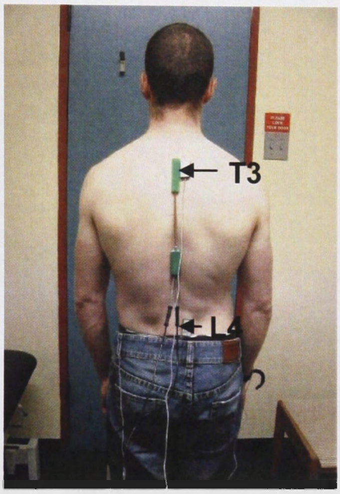


Figure 5.1. The position of the surface EMG electrodes at T3 and L4

5.2.3. The positions

Subjects were asked to perform 8 extension tasks: 6 in prone lying and 2 in sitting. The six prone lying extension tasks are shown in Figure 5.2.

The two extension tasks in the sitting position were performed while sitting erect with arms hanging by the side and the feet supported in front of the body on a 10cm block (40cm deep and 60cm wide) (Figure 5.3). The feet were supported in this way in an attempt to isolate the back extensors by preventing the subjects from pushing through their feet. The wooden chair was 40 cm high and had a flat seat with a non-slip mat on the seat surface (Figure 5.3). The subjects pushed into a hand-held dynamometer (Chatillon MMC series digital dynamometer, AMATEK Inc, Florida, USA) mounted on an adjustable wall-mounted bracket (Figure 5.3). The padded dynamometer transducer head had a flat profile which was specifically made for this study (Figure 5.4). The wall bracket was also constructed for this study. The transducer head was positioned just above the superior margin of the scapulae as described by Mika et al. [321].

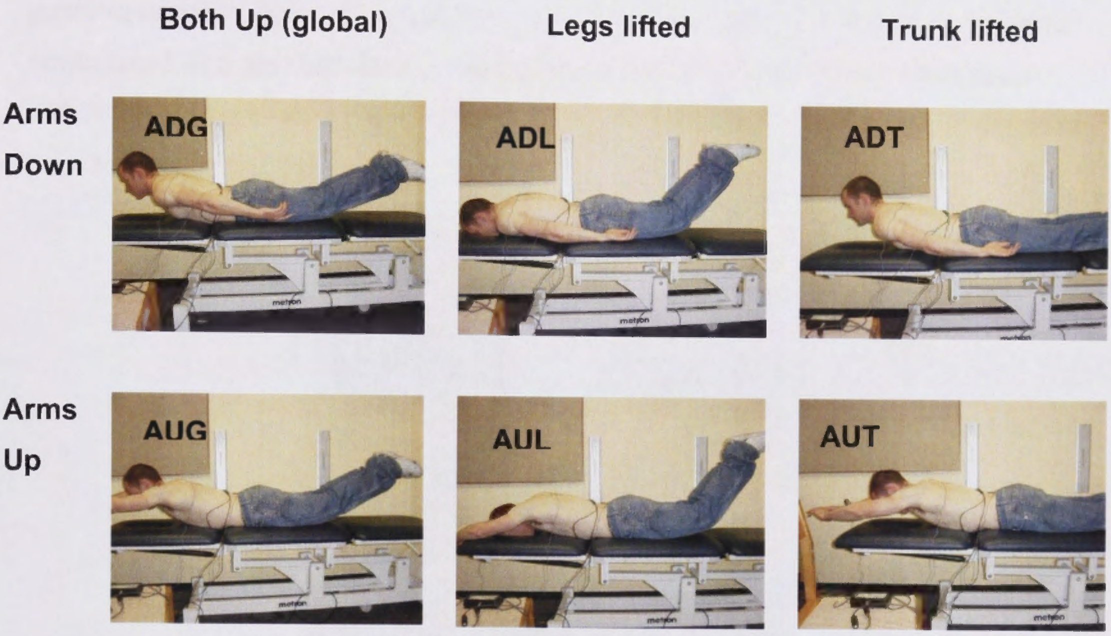


Figure 5.2. The six prone lying extension tasks.

Arms down global lift (ADG); Arms down leg lift (ADL); Arms down trunk lift (ADT); Arms up global lift (AUG); Arms up leg lift (AUL); and Arms up trunk lift (AUT).

The subjects were instructed to let their legs relax and not to push through them. A sign repeating these instructions in large font was placed at a distance of 2 metres from the seated subject at eye level. This sign served to reinforce the verbal instructions but also to keep the subject's head level so that when they pushed into the dynamometer pad they did not hyperextend their neck. The dynamometer was calibrated to zero with the subject leaning forward far enough so that their back was no longer in contact with the transducer. Measurements were made by instructing the subject sit up straight, hang their hands by their side and either: 1) to push into the transducer head as hard as they could without pushing through their feet (EXT); or 2) to pull their shoulder blades back and then push into the transducer head as hard as they could without pushing through their feet (RETRACT). Subjects were verbally encouraged to push as hard as they could for five seconds while at the same time the researcher monitored whether they were pushing through their feet. If subjects used their feet that particular recording was abandoned and another attempt was made after 60 seconds' rest. The order in which the above tests were performed by each participant was randomly allocated prior to commencing the study.

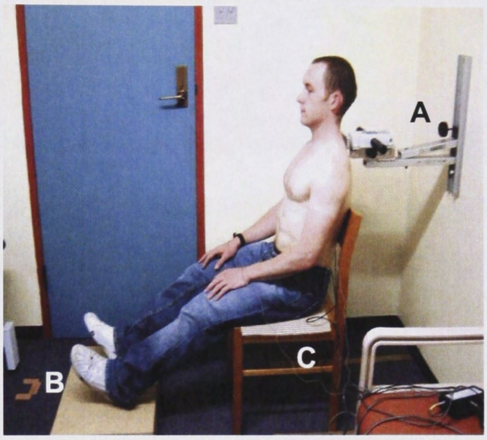


Figure 5.3. The position for sitting extension tasks.

A. hand held dynamometer mounted on an adjustable wall bracket. B. 10 cm wooden block for resting the feet. C. wooden chair with non-slip mat on the seat.

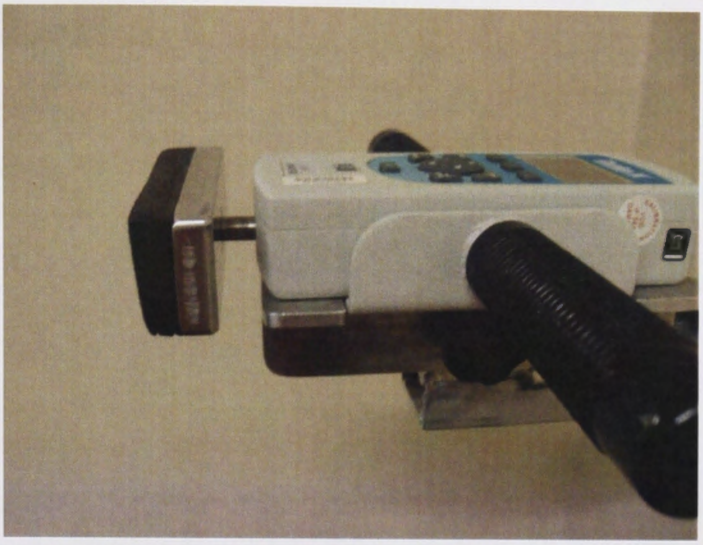


Figure 5.4 Chatillon dynamometer with modified transducer head constructed from an aluminium block covered with high density foam

5.2.4. Data analysis

The statistical software used to make the analyses were Stata version 10.1 (Statacorp, Texas USA) and Genstat Release 13.1 (VSN International, Hemel Hempstead, UK). Normalised sEMG signal amplitudes were summarised as the mean ± standard error. A log transformation of the ratio of normalised TES amplitudes to normalised LES amplitudes (T:L) was calculated to compare the 8 extension tasks for how specifically the TES were activated when compared to the LES, for each extension task. A log transformation of the T:L ratio was used in order to reduce the asymmetry of the ratio data prior to analysis. The normalised signal amplitudes for the TES, LES and the log T:L ratios were compared across all extension tasks: arms down global lift (ADG), arms down leg lift (ADL), arms down trunk lift (ADT), arms up global lift (AUG); arms up leg lift (AUL), arms up trunk lift (AUT), and sitting with scapular retraction (RETRACT); and position (prone or sitting) using a nested analysis of variance (ANOVA) with task and position nested within subject. *Post hoc* analyses of all significant comparisons were performed using least significant difference values (LSDs). Differences were considered significant when $p < 0.05$.

5.3. Results

The mean normalised TES signal amplitude was significantly greater for sitting than for prone ($p < 0.01$) (**Table 5.1**). In terms of individual tasks, the LES signal amplitude was significantly larger in the AUT, RETRACT and AUG tasks ($p<0.001$). AUT was significantly greater than AUG ($P<0.001$) (**Table 5.1** and Figure 5.2).

The mean normalised LES signal amplitude was significantly greater for prone extension than for sitting ($p < 0.01$) (Table 5.1). Although AUT resulted in the maximum LES amplitude, none of the prone task amplitudes was significantly different from any of the others. Although the LES amplitude for the RETRACT task was larger than for EXT the difference did not reach significance (**Table 5.1** and Figure 5.2).

The log ratio of the normalised TES to LES signal amplitude (T:L) was significantly greater in sitting than in prone ($p < 0.001$) (Table 5.1.and Figure 5.6). In terms of the individual tasks T:L in the RETRACT task was largest but it was not significantly different to either EXT or AUT. The log T:L for ADL was the smallest but not significantly smaller than ADG or AUL (Table 5.1.and Figure 5.6).

Table 5.1

Mean normalised sEMG signal amplitudes and log ratio of the normalised thoracic to lumbar amplitudes for each of the extension positions

Position	Task	TES	LES	Log T:L
PRONE LYING	ADG	0.26 ± 0.04	0.74 ± 0.11	- 0.86 ± 0.34
	ADL	0.16 ± 0.04	0.60 ± 0.09	- 1.32 ± 0.44
	ADT	0.39 ± 0.06	0.66 ± 0.08	- 0.44 ± 0.32
	AUG	0.62 ± 0.08	0.78 ± 0.09	- 0.13 ± 0.29
	AUL	0.36 ± 0.05	0.74 ± 0.08	- 0.80 ± 1.17
	AUT*	0.84 ± 0.09	0.79 ± 0.08	0.01 ± 0.26
	Mean of Prone	0.44 ± 0.04	0.72 ± 0.04	-0.58 ± 0.14
SITTING	EXT	0.52 ± 0.09	0.30 ± 0.04	0.52 ± 0.29
	RETRACT†	0.74 ± 0.09	0.40 ± 0.08	0.71 ± 0.35
	Mean of Sitting	0.63 ± 0.06	0.35 ± 0.04	0.61 ± 0.27

Note: Mean ± standard errors.

Abbreviations: Prone positions: ADG, ADL, ADT, AUG, AUL and AUT (Figure 5.2),

Sitting positions: EXT (extension only) and RETRACT (extension with scapula retraction),

Thoracic Erector spinae (TES); Lumbar Erector spinae (LES);

Ratio of normalised TES amplitudes: LES amplitudes(T:S)

*significantly greater than all tasks except RETRACT ($p<0.001$)

† significantly greater than all tasks except AUT and AUG ($p<0.001$)

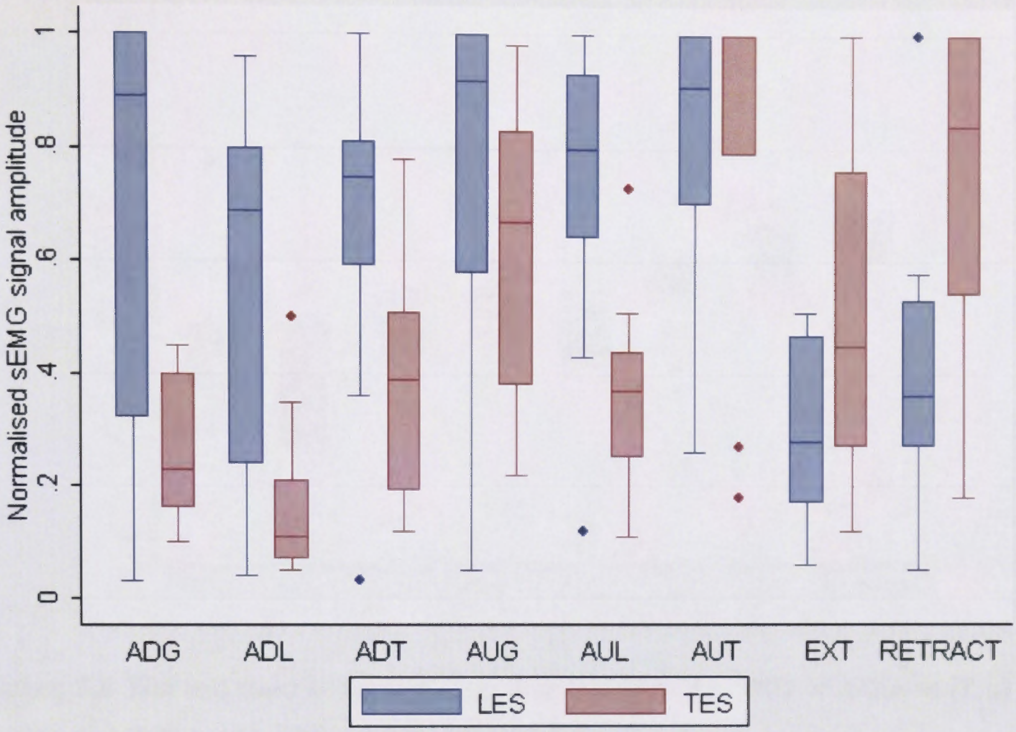


Figure 5.5 Mean normalised sEMG activity of thoracic (TES) lumbar (LES) erector spinae muscles during 6 prone and 2 sitting extension tasks

Note. (Table 5.1 for abbreviations). Box and whisker plot displays medians quartiles and outliers.

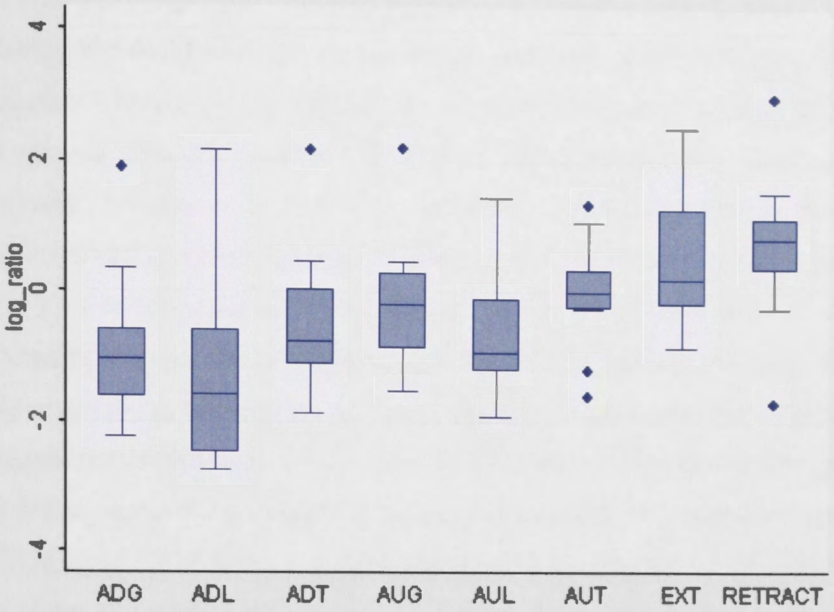


Figure 5.6 The log ratio of normalised thoracic:lumbar EMG amplitude (T:L) during 6 prone and 2 sitting extension tasks.

Note. The '0' on a log_ratio scale corresponds to a ratio of 1. Box and whisker plot displays medians quartiles and outliers.

5.4. Discussion

The aim of this study was to determine whether extension in the sitting position resulted in more TES activity than extension in the prone position. The results showed that prone extension with legs down and arms up (AUT) resulted in the most TES activity followed by extension from sitting with the arms retracted (RETRACT). When TES activity was expressed as a function of LES activity (log T:L ratio) the ratio for both sitting conditions combined was significantly larger than the ratio for the combined prone positions. At first sight this implies that the TES contributed more to the extension effort in sitting.

Extension in prone has been described as both a TES exercise and an LES exercise [36, 566]. The extension exercise which has previously been reported to result in the most LES activity is the arms up global lift (AUG) [566]. Of note, Callaghan and Gunning (1988) calculated that the compression forces produced by the LES during the AUG exercise were so high that they could potentially damage the structures of the lumbar spine [566]. In our study the mean normalised LES amplitude was significantly greater in both AUT and AUG than the other prone tasks. The mean amplitude for AUT was, however, significantly greater than that for AUG indicating that lifting the legs resulted in a reduction in LES activity. The explanation for this probably lies in the contribution of the gluteal and hamstring muscles: Vleeming et al. showed that the gluteal and hamstring muscles are intrinsically attached to the erector spinae muscles via the thoraco-lumbar fascia and are therefore theoretically able to contribute to an extension moment [152]. Therefore, by allowing the gluteal and hamstring muscles to contract in order to raise the legs, the LES would be assisted to extend the spine thereby reducing the amplitude of the sEMG signals from the LES (2.3.12 and 2.4.3.5).

Contrary to our findings, Callaghan, Gunning et al (1998) reported that the mean normalised LES amplitude during AUT was less than half that recorded when the legs were raised (AUG) [566]. The most salient difference between their method and ours was that they strapped their subjects' legs to the table during that AUT task. This would have allowed their subjects to contract their gluteii and hamstrings against the fixed resistance of the strap thereby allowing these muscles to contribute to the production of the extensor moment. In this study, the AUT task required the subjects to raise their trunk while being verbally encouraged to keep their legs down. In this situation, the gluteal and hamstring muscles would not have been in a position to assist to any great degree thereby making the LES the sole prime movers for the task. Hence the relatively higher amplitudes for the AUT task than for the AUG task. This observation is relevant to the prescription of extension exercise in that, if AUG produces very high lumbar spine compression loads [566], then the loads produced during AUT without fixing the legs would presumably result in even greater loads. Although not the focus of this experiment, this observation has implications for spinal rehabilitation.

Resisted isometric extension in sitting resulted in significantly lower LES amplitudes compared to the six prone extension exercises. This is not surprising as extra LES activity was required to overcome the weight of the trunk generated by gravity. In sitting, the transducer head against which the subjects pushed was positioned at approximately T3 in order to maximize the activity of the TES [321]. The lower LES amplitudes which were recorded in sitting suggest that extension in the sitting position resulted in significantly lower lumbar spine compression forces. However, Callahan, Gunning et al. (1998) recorded a total of seven trunk muscles (right and left) from which they built their model and calculated the forces. Presumably the abdominal muscles would have contributed significantly to the estimated compression forces during extension exercises since they, and the external oblique muscles in particular, have been reported to be involved in pre-loading the spine during tasks which require trunk stiffening [218]. Although the subjects in this study reported that the abdominal activity in prone was as high, or higher than in the sitting tasks, abdominal activity was not specifically measured and so the influence of additional spinal compression from abdominal muscle activity in sitting cannot be discounted. Further, extension forces generated during prone extension compared to resisted extension in sitting were not measured and so whether maximal extension effort in prone was the same as maximal extension effort in sitting remains uncertain. A further study would be needed to clarify these points.

The arms down trunk lift (ADT) extension task (Figure 5.2) has been used extensively as a thoracic extension strengthening and testing exercise (Limburg, Sinaki et al. 1991; Itoi and Sinaki 1994; Miyakoshi, Hongo et al. 2005; Kasukawa, Miyakoshi et al. 2010). The results of this study indicated that the TES amplitudes were low in this position. In fact, the mean amplitude was approximately half that of the sitting with retraction task. On the other hand, the mean LES amplitude during ADT was relatively high generating a negative log T:L ratio. These findings support the hypothesis that ADT is more of a lumbar extension exercise than a thoracic extension exercise and almost certainly explain why the subjects in Itoi and Sinaki's study who performed the ADT task for two years did not exhibit a significant difference in their kyphotic angle when compared to a control group [10].

The current study has a number of limitations. The numbers were small and the results therefore exhibited fairly large variance. One subject (an older male) was a distinct outlier who opposed the trend for all the other subjects demonstrating low TES values in sitting and low LES amplitudes in prone. However, the data still showed a significant difference between prone and sitting (with very low p values). Another limitation is that the sEMG data were normalised using the maximum amplitude recorded during any of the extension tasks. This maximum value was generally seen in the AUT task but for some subjects other tasks resulted in the maximum value. The data was normalised as a function of the maximum amplitude regardless of which position it was achieved in. Extension in prone was not resisted except by gravity and had this been done higher amplitudes from which to normalise the data may have been recorded. Using maximum voluntary isometric contraction (MVIC) to normalize sEMG data is commonly reported in the literature but it is not necessarily a superior technique (2.7.2). In fact, submaximal normalisation has been shown to be more reliable and repeatable [442].

Finally, the results appear to support the hypothesis that the TES are more active in extension from sitting than they are in prone lying. However, the fact that scapular retraction increased the normalised TES amplitude so much is suspicious. It is possible that the T3 recording electrodes may have been recording the trapezius muscle rather than the thoracic erector spinae. The study conducted by de Sèze and Cazalet (2008) which recommended the T3 site suggested that it would be superior to the commonly used T9 site, was an anatomical study conducted on cadavers. It is possible that the aponeurotic window that they discovered adjacent to T3 is not present, or perhaps not as wide, *in vivo*. This pilot study is therefore not able to conclude that the sitting position better targets the TES. Nevertheless it is still concluded that the LES are significantly more active during prone extension than they are during sitting extension.

5.5. Conclusions

Extension exercises performed in prone target the lumbar extensors. Extension exercises in sitting possibly target the thoracic extensors more effectively, but this has not yet been proven. Further studies are required to evaluate the extent and the nature of the differences between these exercise positions. However, prior to any further examinations of the erector spinae using sEMG, the anatomical validity of the recording sites needs to be established.

Chapter 6.

Ultrasound Evaluation of Thoracic and Lumbar Erector Spinae Surface EMG Recording Sites

This chapter has been published as Perriman, D.M., et al., *Ultrasound assessment of the anatomical validity of T3 and L4 as sEMG recording sites.* Journal of Biomechanics, 2011. **44**: p. 1025 - 1030.

6.1. Introduction

In the previous chapter the results of a study which set out to measure the activity of the thoracic and lumbar erector spinae muscles during prone and sitting extension were questioned. It was hypothesized that the activity recorded at the thoracic recording site adjacent to T3 may have originated from the superficial muscles rather than the deeper erector spinae. In this chapter a study designed to explore this possibility will be reported.

6.2. Background

Surface electromyography (sEMG) has been used extensively to measure muscular activity in the thoracic and lumbar erector spinae muscles [218, 219, 366, 425, 427-433, 435, 569, 570]. It has advantages over needle electromyography (nEMG) in that it is non-invasive, painless and capable of measuring electrical activity from whole muscles rather than from single motor units [436]. This makes sEMG an ideal tool for measuring muscle activity during functional activities in which nEMG needles might become dislodged or cause pain thereby potentially inhibiting normal activation [439][439][439][439][438, 439]. Although sEMG has been used to estimate the activity of deeply-situated muscles either directly [571] or by a process of cross-correlation [572], the signal is dominated by the most superficial muscles under the recording electrodes [439, 573]. Thus, if the aim is to measure deeply situated muscles, the superficial muscles will give rise to significant cross-talk or interference unless they are completely inactive. [436, 439].

The erector spinae muscles (ES) which run the length of the dorsal trunk, are deeply situated. The thoraco-lumbar fascia overlies them along the entire length of the spine [152, 165]. This fascia widens over the upper thoracic and lumbar regions where it acts as an aponeurosis connecting superficial muscles to the spinous processes [154]. In the lumbar spine the fascia is thick and broad but in the thoracic spine it is thinner and narrower [164, 165].

In theory, therefore, the widened areas of thoraco-lumbar fascia should provide several electrically silent windows for sEMG of the ES [154]. Previous researchers have used numerous sites from which to record the ES (see Table 6.1), but they have done so without much consideration of these windows. In general, the selection of recording site has been made on the basis of prior use (Table 6.1).

The recording sites used by researchers exploiting these windows have varied widely between T3 and L1 for the thoracic ES; and L3 to S2 for the lumbar ES.

It is widely accepted that lumbar recording sites are relatively unaffected by extraneous signal from other muscles. However, there is less certainty about thoracic sites. Floyd and Silver (1955) were the first to experiment with sEMG of the ES [574]. They positioned their ES recording electrodes adjacent to the spine at various locations and noted that in order to ensure no ‘pick-up’ from the trapezius and latissimus dorsi muscles, the arms and shoulders were required to be inactive and had to hang down loosely under gravity. In a later study Lafortune et al (1988) determined that the thoracic ES could be faithfully recorded 40 mm lateral to T9 because this site yielded the same sEMG amplitudes as a site 30 mm lateral to L4 [427]. This ‘evidence’ has subsequently been widely cited (Table 6.1). Nevertheless, concern that the ES recording sites had not been adequately validated prompted a recent anatomical study by de Sèze and Cazalets who sought to identify the optimal ES recording sites for sEMG using cadaveric dissection [154]. They found fascial windows through which the ES could theoretically be recorded at C7, T3, and T12 to L4, with T3 and L4 being the most reliable sites. The site adjacent to T9 was found to be covered by the trapezius and or latissimus dorsi muscles in all cases.

The sites identified by de Sèze and Cazalets were, however, identified on cadavers and it remains possible that the extent of the fascia is different in live subjects for a number of reasons. First, cadaveric muscle architecture differs from living muscle architecture: aged and preserved tissues can be flattened and thinned making it difficult to find margins between contractile and non-contractile tissues [575, 576]. Second, the resting position of muscle after death may be different to that during life [577]. Third, stretching a muscle by changing the position of the arms or shoulders may affect the relative extent of the fascia. And, finally, the cadavers used in de Sèze and Cazalets' study were presumably elderly which may limit the application of their findings to studies of elderly populations.

Accordingly, the aim of this study was to measure the width of the fascial windows (aponeuroses) in live subjects using real-time ultrasound imaging (US). On the basis of de Sèze and Cazelets' findings [154], the aponeuroses at T3 and L4 were selected as potential sites for sEMG of the thoracic and lumbar ES, respectively. Measurements were made on a group of younger (<30 years) and a group of older (>70 years) participants to assess the effect of aging.

Table 6.1 Previously published thoracic erector spinae sEMG recording sites

Paper	Erector Spinae sEMG electrode placement	Justification for electrode site	Main conclusions from thoracic recording
Floyd and Silver (1951) [425]	Lateral to T10, T12, L2 and L4	"we have some evidence to show that the upper part of the muscle in the thoracic region behaves the same way as the lumbar part"- not specified.	Full spinal flexion leads to relaxation of all the erector spinae muscles.
Schultz et al.(1982) [426]	30 mm lat toT8 20 mm lat to L3	None	Didn't really use the results – "similar to L3"
Lafortune et al.(1988) [427]	50 mm lat to T9 Lat to L2 and above PSIS 30 mm lat to L3	Recordings over T9 and L3 site show insignificant differences in 8 young males during a lifting task.	sEMG recordings 30 mm lat to L3 may represent activity in upper paraspinal muscles.
McGill (1991) [428]	50 mm lat to T9 30 mm lat to L3	Lafortune (1988) [427]	Thoracic (and lumbar) ES perform a balancing and stabilizing role while other muscles generate axial torque
McGill (1992) [429]	50 mm lat to T9 30 mm lat to L3	None	During torsion the lumbar and thoracic erector spinae behave similarly.
Cholewicki and McGill (1996) [219]	50 mm lat to T9 30 mm lat to L3	None	EMG assisted algorithm suggests low load tasks may cause lumbar spine buckling.
Seelen et al. (1998) [430]	25 mm lat toT3and T9 25 mm lat to L3	None	Low thoracic SCI patients recruit LES and TES for sitting balance
Krajcarski et al. (1999) [218]	40 mm T9 30 mm L3	McGill (1992) [429]	Thoracic and lumbar ES stabilise the trunk better after preloading.
Callaghan and Dunk (2002) [431]	50 mm T9 30 mm lat L3	McGill (1991) [428]	Slumped sitting led to flexion relaxation in TES but not LES.
Mosely et al. (2003) [432]	50 mm lat T7	None	TES switch on prior to multifidus in response to perturbation.
Abdoli-E et al. (2006) [433]	50 mm T9 30 mm L4	None	Lift device reduced activity in TES
O'Sullivan et al. (2006) [578]	50 mm lat to T9	Callahan and Dunk (2002) [431]	TES more active in 'thoracic' sitting therefore produce higher compressive loads and fatigue more quickly.
Greig et al. (2008)[366]	Lateral to T8 Lateral to L3	Schultz (1982)[426]	No change in thoracic sEMG with change in walking surface whereas there was in the lumbar spine
Cholewicki et al. (2009) [435]	50 mm lat to T9	Cholewicki and McGill, (1996) [219]	Sig. diff in TES activity during static traction compared to sinusoidal traction.

Note. Examples of papers which have used surface EMG (sEMG) to evaluate the thoracic erector spinae (TES); the recording sites used; their justification for the sites chosen and the main conclusion with respect to their thoracic recordings. The citation trail leads either nowhere, or to Lafortune et al. whose findings, which were published only in conference proceedings, were speculative. All measurements are expressed in mm for consistency.

6.3. Methods

6.3.1. Subjects

A power analysis based on de Sèze and Cazelets' results indicated that ten subjects in each age group would be sufficient to address the hypotheses. Accordingly, twenty healthy volunteers were recruited for this study by advertisement in a hospital. Ten subjects were included in the younger group (aged between 18 and 30 years) and ten were included in the older group (over 70 years). There were equal numbers of males and females in each group. The subject demographics are shown in Table 6.2. Exclusion criteria included previous significant spinal problems such as: fracture, surgery, spinal disease, thoracotomy, pregnancy, neuropathy or myopathy. All subjects gave informed consent. Ethics approval for this study was granted by the ACT Health Human Research Ethics Committee and the Australian National University Human Research Ethics Committee.

Table 6.2

The subject demographics

Age category	Age (years)	Weight (kg)	Height (cm)
<30	23.9 (1.8) [21 – 27]	68.3 (10.8) [55 – 91]	173.6 (11.1) [157 – 190]
>70	76.1 (4.6) [70-84]	73.2 (8.7) [57 – 88]	173.3 (11.5) [161 – 197]

Note. Mean, (standard deviation) and [range]. The younger (<30) and the older (>70) groups each included 5 males and 5 females.

6.3.2. The ultrasonic measurements

Ultrasonography was performed under the guidance of a trained sonographer using a Mindray DP-6600 ultrasound scanner with a 3.5 MHz R50 electronic convex array transducer (Mindray Biomedical, Shenzhen, China).

The participants were positioned in prone lying. After palpating all of the spinous processes, the T3 and L4 spinous processes were marked with ink. The US transducer head was positioned to the right of the T3 and L4 spinous processes since aponeurosis widths have been reported to be symmetrical [154]. The prone lying US images were acquired in each of three positions: arms above the head (P1), arms hanging by the side (P2) and arms lying alongside the body (P3) (Figure 6.1). These positions were chosen in order to examine the effect of changes in the position of the superficial muscle groups on the T3 aponeurosis width. The order in which the subjects assumed each position was randomised and after each change of position the locations of the spinous processes were reassessed. For each of the three positions US images were acquired at rest and then again during sustained back extension from prone, resulting in a total of six images adjacent to T3. Thereafter six images adjacent to L4 were recorded in the same way.

Figure 6.1. Subject 1 performing the active extension task in the P1 (prone arms above head), P2 (prone arms hanging), and P3 (prone arms by side) positions.

Note. The markers seen attached to the back of this subject were used in the kinematic study described in the following chapter. The photographs are included here for the clarification of the test positions only.

Measurements of the aponeurosis widths were made offline from the US images. At T3, aponeurosis width measurements were made by identifying the hyper-echoic fascial lines situated above and below the trapezius muscle and measuring the distance between the point where they coalesced (the medial edge of the muscle) and the tip of the spinous process (Figure 6.2). L4 aponeurosis width measurements were made by identifying the fascial lines above and below the latissimus dorsi and measuring the distance between the point just lateral to where they coalesced and the tip of the spinous process (Figure 6.3). If an image was insufficiently clear to delineate the muscle edge and the point at which the fascia coalesced to become the aponeurosis precisely, a conservative judgment in favour of a greater aponeurosis width was made. All measurements were made with the linear measurement software incorporated within the Mindray system (Figure 6.2 and Figure 6.3).

6.3.3. Statistical analysis

The data for each group were expressed as mean and standard deviations (mean (± SD)). Ranges were reported separately in the tables.

Differences between the aponeurosis widths at the thoracic and lumbar sites were analysed using a split-plot ANOVA model with age group and gender as between-subject effects, and activity (at rest and in extension), arm position and arm position order as within-subject effects.

Differences were considered significant when $p < 0.05$.

6.4. Results

6.4.1. Thoracic (T3)

The mean aponeurosis width between the tip of the spinous process of T3 and the adjacent trapezius muscle was significantly smaller during extension than at rest (1.8 ± 2.6 mm and 4.35 ± 4.7) mm respectively, $p < 0.0001$; Table 6.3 and Figure 6.4). Neither arm position nor the order in which the positions were assumed had a significant effect on aponeurosis width. Overall, males had significantly smaller mean aponeurosis widths than females ($p = 0.049$; Table 6.3 and Figure 6.4). This difference was most marked in the young males who had mean width measurements approaching zero during both rest and extension, contrasting with both young females and the older group, all of whom had mean aponeurosis widths of between 5.6 and 5.9 mm at rest (Table 6.3 and Figure 6.4).

6.4.2. Lumbar (L4)

The mean aponeurosis width between the tip of the spinous process of L4 and the medial edge of the adjacent latissimus dorsi muscle was significantly smaller during extension than at rest (29.4 ± 7.2 mm and 35.5 ± 7.0 mm respectively, $p < 0.0001$). The difference between L4 aponeurosis width at rest and in extension was significantly affected by arm position ($p < 0.05$) with larger differences in the P3 position (arms along-side) compared to P1 and P2. This was primarily influenced by the older subjects because it was not marked in the younger group ($p < 0.01$). As was the case with the T3 measurements, the order in which the positions were assumed did not have a significant effect on aponeurosis width.

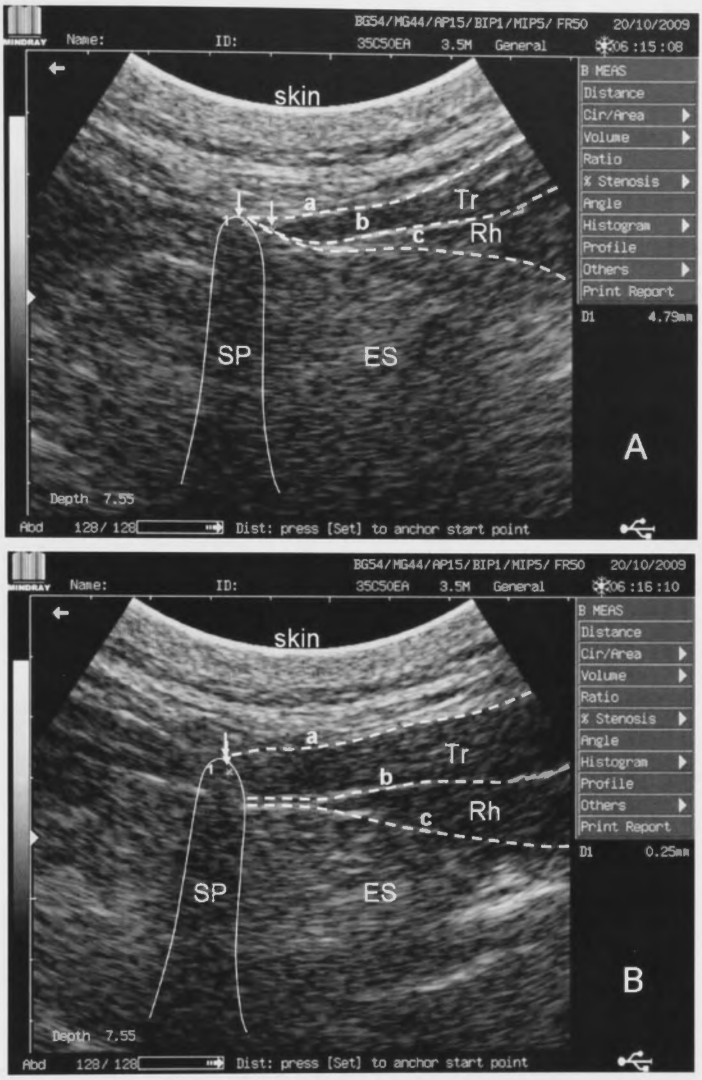


Figure 6.2 US images of the T3 spinous process (SP) with the attachments of the right trapezius (Tr), rhomboids (Rh) and the erector spinae (ES).

(A) at rest and (B) in extension. Arrows indicate the points between which the aponeurosis width measurement was made. Three layers of fascia are identified: the trapezius aponeurosis (a), the rhomboid aponeurosis which is continuous with the superficial lamina of the posterior layer of the thoraco-lumbar fascia (b), and the deep lamina of the posterior layer of the thoraco-lumbar fascia (c). The trapezius aponeurosis was seen to be separate from the rhomboid aponeurosis during extension.

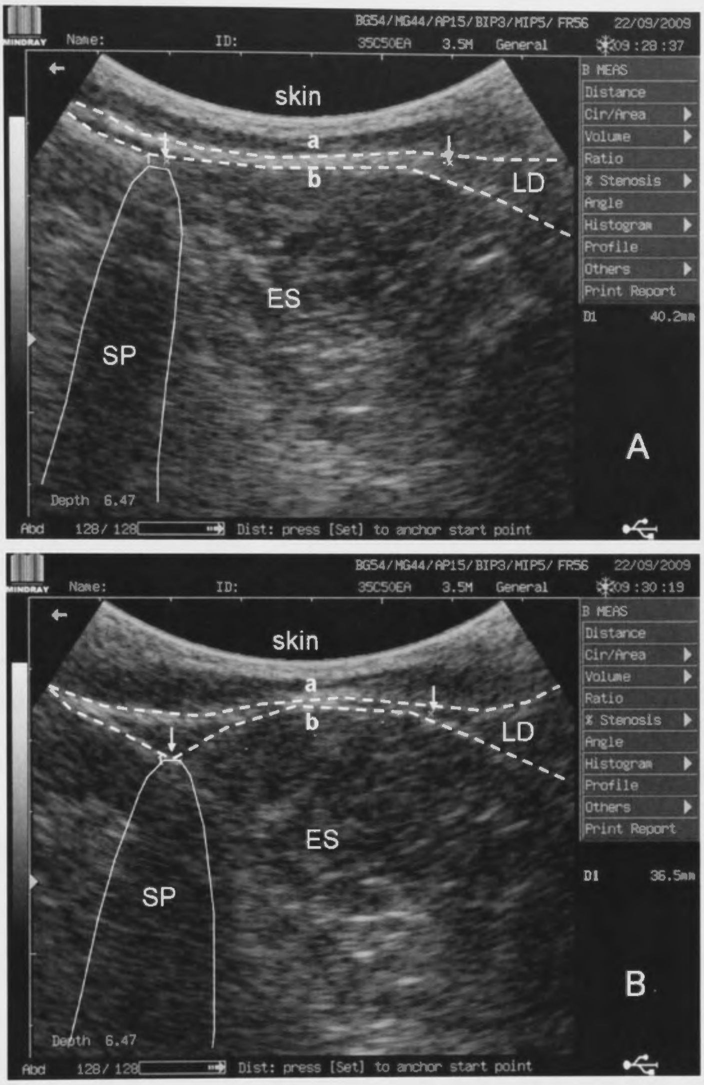


Figure 6.3 US images of the L4 spinous process (SP) with the attachments of the right latissimus dorsi (LD) and the erector spinae (ES).

(A) at rest and (B) in extension. Arrows indicate the points between which the aponeurosis width measurement was made. Two layers of fascia are identified: the latissimus dorsi aponeurosis which is continuous with the superficial lamina of the posterior layer of the thoraco-lumbar fascia (a), and the deep lamina of the posterior layer of the thoraco-lumbar fascia (b). The two layers were pushed upwards during extension into a domed shape due to the contraction of the ES resulting in a narrowing of the aponeurotic window.

Table 6.3

Measurements of aponeurosis width (mm) during rest and extension

		All subjects	<30 years		> 70 years	
T3		Females & Males	Female	Male	Female	Male
Rest**	mean (SD)	4.4 (4.7)	5.6 (5.8)	0.3 (0.7)*	5.9 (3.8)	5.6 (4.6)
	range	0 – 21.2	0 – 21.2	0 – 2.3	0 – 10.7	0 – 17.4
Extended	mean (SD)	1.8 (2.6)	2.3 (2.3)	0.2 (0.4)*	3.4 (3.3)	1.4 (2.2)
	range	0 – 9.1	0 – 8.2	0 – 1.2	0 – 9.1	0 – 5.9
L4						
Rest†	mean (SD)	35.5 (7.0)	36.8 (4.6)	40.4 (4.8)	30.3 (5.2)	34.7 (8.9)
	range	18 – 52.8	28.1 – 44.9	29.8 – 48.7	18 – 38.8	25.2 – 52.8
Extended	mean (SD)	29.4 (7.1)	25.9 (8.4)	33.1 (5.4)	25.5 (6.1)	31.6 (9.5)
	range	14 – 52.6	19.6 – 35.3	24.9 – 42.9	14 – 33.2	22.8 – 52.6

Note. Measurements are in mm. Twenty subjects <30 years of age (n=10) and >70 years (n=10) at T3 and L4. The measurements at rest and during extension in prone are presented separately.

* Male aponeurosis width significantly smaller than female p = 0.049

** Significantly larger aponeurosis width than when extended p < 0.0001

† Significantly larger aponeurosis width than when extended p < 0.0001

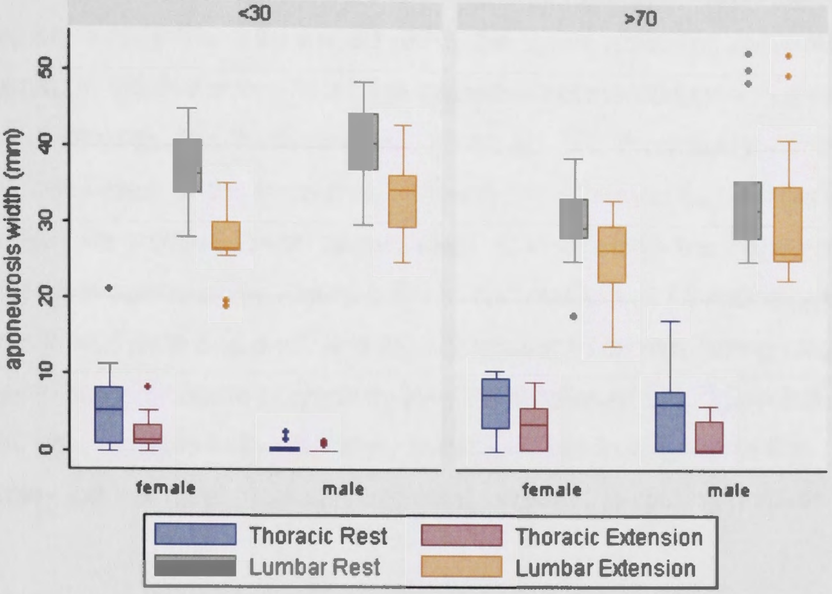


Figure 6.4 **Boxplot of the aponeurosis widths at T3 and L4 during rest and extension for the males and females in both the younger and older age groups.** The aponeurosis width at rest was significantly wider than in extension at both sites ($p < 0.0001$). Males had significantly narrower T3 aponeurosis widths than females ($p < 0.05$).

6.4.3. The dynamic muscle behaviour and the aponeurosis

The appearance and behavior of the aponeuroses in the thoracic and lumbar regions were very different. The most superficial muscle at the thoracic site was the trapezius. At rest, this muscle was attached to the T3 spinous process via a clearly visible aponeurosis in fifteen out of the twenty subjects. In the remaining five subjects the muscle inserted directly onto the spinous process with no discernable aponeurosis. Where an aponeurosis was present, its width decreased during active extension. In three of the fifteen subjects who had a discernable aponeurosis at rest, it was reduced to nothing during extension. When present, the aponeurosis appeared to connect both the trapezius and the rhomboid muscles via a single structure at rest, but during extension it was seen to cleave horizontally as the trapezius muscle fibers thickened within the space revealing separate attachments. In the five subjects whose trapezius appeared to insert directly onto the spinous process, this thickening was profound. The rhomboid muscle, which was positioned deep to the trapezius, increased in thickness but always inserted onto the spinous process via an aponeurosis situated below the trapezius muscle or the trapezius aponeurosis Figure 6.2. I In contrast to the T3 aponeurosis, the L4 aponeurosis was wide and thick and did not appear to cleave during extension but was seen to bulge or dome posteriorly over the thickened ES Figure 6.3. The latissimus dorsi muscle belly was seen to thicken, but its relation to the aponeurosis did not differ markedly from that seen in the resting position (Figure 6.3).

6.5. Discussion

The aim of this study was to investigate the utility of two recently-proposed sEMG recording sites for the ES *in vivo*. Four major findings were made. First, the most superficial aponeurosis width adjacent to T3 was either non-existent or too narrow to allow sEMG recording. Second, the aponeurosis width at both T3 and L4 reduced significantly during active back extension. Third, the aponeurosis width at T3 was significantly narrower in men than in women, with young men often demonstrating no discernable aponeurosis at all. Finally, the trapezius muscle attached to the spinous process at T3 within an envelope of connective tissue which was separate to the aponeurosis of the rhomboid muscle lying below it. These findings have not previously been reported in the literature.

The accuracy of direct recordings of muscle sEMG amplitudes critically depends on the positioning of the recording electrodes so as to avoid interference or ‘crosstalk’ from other muscles [439]. The ES have been studied using sEMG for nearly 60 years (Table 6.1). Surface EMG recording electrodes for the thoracic ES are most commonly sited in the lower thoracic spine because of concerns over interference from the trapezius and rhomboid muscles [425]. The most common site used is 40 - 50 mm adjacent to T9 [428, 431]. This site was first suggested by Lafortune et al. (1988) who found that the sEMG signal amplitudes measured here and 30 mm adjacent to L4 were the same. The recordings were made from eight young men while they performed squat lifts [427]. Until now this site has been the accepted standard for electrode placement.

As noted previously, recent anatomical evidence has suggested that recordings made adjacent to T9 are likely to be subject to significant crosstalk [154]. Cadaveric dissection revealed that the thoracic ES were covered by superficial muscle tissue from T5 to T11 but de Sèze and Cazalets suggested that there was an 'electrically silent window'between C7 and T4 through which the thoracic ES could potentially be recorded. This window was widest at T3 with a mean width of 34 mm. They recommended positioning sEMG electrodes 20 mm from the midline at T3. Other investigators have located their electrodes 25 mm adjacent to the T3 spinous process (Seelen, Potten et al. 1998). Our *in vivo* study demonstrated, however, that the mean T3 aponeurosis width at rest was only 6 mm reducing to 3 mm during active back extension. Thus, according to our results the sites suggested by de Sèze and Cazalets and those used by previous researchers would lie over the belly of the trapezius muscle. The T3 site is therefore not suitable for sEMG recording of the thoracic ES *in vivo*, especially during functional activities, unless the trapezius and rhomboid muscles are specifically rendered completely inactive. In the light of both our results and those of de Sèze and Cazalets the findings of previous studies which have used sEMG to record the thoracic ES may need reconsideration (Table 1).

Although difficult to obtain directly, the activity of deeply-situated muscles can be inferred from sEMG. McGill et al. (1996) hypothesized that deep trunk muscle activity could be predicted from surface activity because the neural drive to both is matched. They found that the difference in amplitude between superficial and deep recordings was generally within 15% and argued that this magnitude of error was within acceptable limits for biomechanical modelling [571]. Whether there is a uniform relationship between the surface muscles and the deeper thoracic ES has not yet been established.

The suitability of L4 as a recording site is not in dispute and the findings of this study confirm that the aponeurosis adjacent to L4 is sufficiently wide for direct sEMG recording. de Sèze and Cazalets recorded a mean aponeurosis width of 86 mm and therefore recommended that sEMG electrodes be sited at a distance of 40 mm from the midline at L4 [154]. Many previous studies have used distances of between 20 and 30 mm (Table 6.1). Importantly, our study showed that the mean aponeurosis width reduced significantly in extension from 35.5 mm to just 29 mm. This reduction in aponeurosis width was the result of a 'doming' effect produced by the contraction of the underlying ES during active extension (Figure 6.3). In fact, this 'doming' can easily be observed from the skin surface but this is the first time that the effect on the aponeurotic window has been reported. Our results indicate that if subjects are to be studied during extension a distance of 20 mm from the L4 spinous process would ensure that the electrodes were positioned over the aponeurosis, thereby preventing crosstalk from the latissimus dorsi.

The finding that the lumbar aponeurosis width may be less wide during strong contraction of the erector spinae is relevant to the findings of Lafortune et al. (1988). As previously noted, their assertion that the T9 site records the thoracic ES rests on the fact that the lumbar ES signal amplitudes measured at 30 mm adjacent to L4 were the same as the signal amplitudes measured 40 mm lateral to T9. In this study the aponeurosis width at L4 in young males during extension was a mean of 33 mm, so siting the recording electrode at 30 mm may have resulted in crosstalk from the latissimus dorsi. Further, the site adjacent to T9 is completely covered by the muscle fibres of either the trapezius or latissimus dorsi [154] raising the strong possibility that the signal detected by Lafortune et al. may actually have arisen from the latissimus dorsi which would have been strongly activated during the squat-lift protocol used in their study.

Arm position did not affect the aponeurosis width at T3. Changes in arm position were included in order to evaluate whether the T3 aponeurosis width was significantly affected by differences in scapular and arm position. The results indicated that it was not.

The US images of the aponeurosis showed that the rhomboid and trapezius muscles were surrounded by separate fascial layers which, in most cases, coalesced to form their aponeurotic attachments onto the spinous process. For trapezius, the extension task demonstrated this arrangement very clearly: the muscle expanded within its fascial envelope during contraction, dramatically reducing the fascial window and removing the possibility of any 'electrically silent' access to the ES muscles below. This configuration is consistent with descriptions of the trapezius lying between two laminae of the deep cervical fascia [106]. The rhomboid aponeurosis did not appear to reduce in length during the extension task. The images of the lumbar aponeurosis were consistent with previous anatomical descriptions [164, 165, 167, 579].

The limitations of this study include small sample size and limited US quality. Though small, the number of subjects used in this study was sufficient to address its main aim. A larger cohort might further clarify the age and gender effects which we observed. A 3.5 MHz transducer was used to acquire the images for this study. A higher frequency US unit would undoubtedly have resulted in more detailed images [576]. To overcome this potential limitation, we were conservative in our measurements in cases where clarity of image was an issue, reporting larger width measurements in all cases. We are therefore confident that the results do not underestimate aponeurosis width. Finally, because the study participants were only positioned in prone lying extrapolating our findings to other positions should be done with caution.

6.6. Conclusion

This study reveals the potential risks of extrapolating findings from cadaveric studies to living systems. It transpires that T3 is not a reliable site over which to record the ES directly *in vivo* because the trapezius muscle, when contracted, covers the ES. This is consistent with the suggestion that many previous studies which have purported to measure the thoracic ES using sEMG have, in fact, recorded activity from the superficial muscles. In the lumbar spine we would recommend electrode placement no further than 20 mm adjacent to L4. On the basis of our results, future researchers are encouraged to re-examine the use of sEMG to study the ES. In theory, nEMG would be more accurate but the difficulties associated with its use make it less practical. An alternative approach would be to use sEMG and compensate for crosstalk from superficial muscles by employing techniques which use a larger number of recording sites along with more advanced signal processing analysis.

The results of this study show that the findings of the sEMG pilot study described in chapter 5 were, as suspected, probably erroneous since the trapezius is very active during extension activities and would have been primarily responsible for the electrical activity detected at the T3 recording electrode. Consequently two alternative methods of evaluating the contribution of the thoracic extensors will be explored in the next chapter.

Chapter 7.

Thoracic Extension – Prone or Sitting?

7.1. Introduction

This chapter contains the descriptions and results of two studies which were designed to compare the prone lying extension with seated extension for thoracic extension movement and thoracic erector spinae activity. Although each study stands alone in terms of the conclusions reached, the primary purpose of conducting these studies was to devise an effective intervention strategy and testing protocol for the RCT described in chapter 9. The first study aimed to investigate the differences between prone and sitting extension in terms of thoracic and lumbar inter-segmental movement and the results contributed to the design of the second study. The second study aimed to re-examine the extent to which the thoracic and lumbar erector spinae muscles are active in extension from prone lying versus sitting. Because direct measurement was not possible, force measurements were combined with sEMG of the lumbar erector spinae to evaluate the relative contributions of the thoracic and lumbar erector spinae.

7.2. The thoracic and lumbar extension kinematic study

7.2.1. Background

Spinal inter-segmental movement has been investigated both *in vitro* and *in vivo* (2.2.3). The *in vitro* study reported that the amount of flexion and extension at each thoracic motion segment increased in a cephalo-caudad direction [47]. The *in vivo* measurements were made with an electromagnetic tracking system (2.6.4.2) and also reported increasing mobility in a cephalo-caudad direction but the ranges in the lower segments were only 6° compared to those measured *in vitro* which were 9°-12° [49]. The aforementioned studies were performed with the spine in the upright position. The inter-segmental movement of the thoracic spine during prone has not yet been investigated.

Prone extension has been reported to be effective as both a lumbar extension strengthening exercise [566, 567], and a thoracic extension exercise [10, 580]. As has been discussed previously (2.7.1 and 2.9.2.2), prone lying is the most common position in which to measure thoracic extension strength [10, 74, 423] and although sitting has also been used, the methodology has most commonly involved using seated dynamometers designed for lumbar extension tasks rather than thoracic extension [8, 424]. The extent to which the thoracic spine extends in prone lying compared with erect sitting, and the extent to which the thoracic spine extends compared to the lumbar spine, have not been investigated.

Prone extension can be performed with the arms in different positions (Figure 7.1). The difficulty of the extension task is subjectively increased with the arms above the head (Figure 7.1, P1) [566] and decreased when the arms are positioned alongside the body (Figure 7.1, P3). The effect of arm position on inter-segmental movement has not been examined.

Scapular retraction is related to more upright posture in women over 50 years [581] and is often used to enhance thoracic extension. There have not, however, been any studies which have measured the effect of scapular retraction on thoracic inter-segmental extension.

The effect of age and gender is particularly pertinent to the study of thoracic extension exercise and testing. Most of the research in this area has been conducted on, and for, older women for whom hyper-kyphosis is both a cosmetic and a health risk (2.2.6). It is important that the differential efficacy of exercise strategies in the old and the young, as well as in males and females, is understood in order that appropriate and effective exercises are prescribed.

As mentioned above, thoracic inter-segmental movement has been measured using an electromagnetic tracking device but less complex methods are also appropriate for this measurement. Because extension is limited to the sagittal plane, it is possible to capture the inter-segmental excursion reliably using single camera photography and retro-reflective balls (skin markers) (2.6.3.5). Photography has been shown to be reliable and accurate for the measurement of static postures when the camera position is standardised and positioned at the centre of the segment being measured [371, 372].

Accordingly, the aim of this experiment was to determine whether sitting or prone extension exercises produce the most inter-segmental extension of the thoracic spine and whether arm position in prone, and scapular position in sitting, had an effect. A further aim was to determine whether there is an effect due to age and/or gender.

7.2.2. Method

7.2.2.1. Subjects

The subjects for this study were those used in chapter 6 (Table 6.2) and the same exclusion criteria and ethical approvals applied.

7.2.2.2. The extension tasks

Five extension tasks were performed in this experiment. Three of these tasks were performed in prone lying and two were performed in sitting. The five tasks are shown in Figure 7.1. P1, P2 and P3 (the prone extension tasks) have been described previously in chapter 6 (Table 6.2). The sitting tasks were: extension in sitting without scapular retraction (S1), and extension in sitting with scapular retraction (S2).

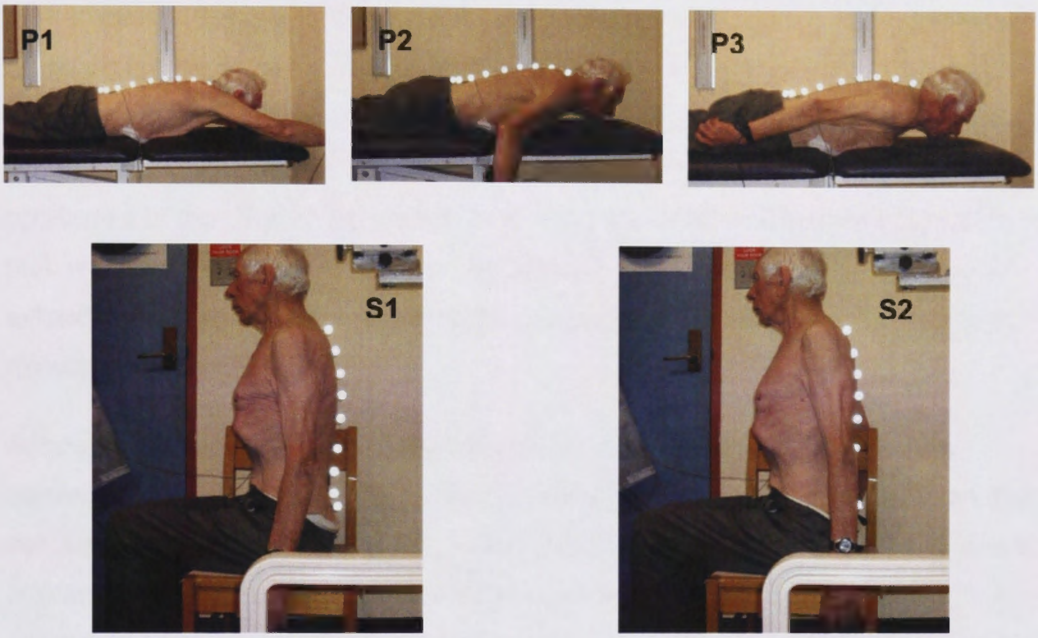


Figure 7.1. Subject 1 performing the P1 (prone arms above head), P2 (prone arms hanging), P3 (prone arms by side), S1 (sitting extension only) and S2 (sitting extension with scapula retraction) tasks.

7.2.2.3. The kinematic measurements

The participants were positioned in prone lying on a plinth which was adjusted to a height of 52 cm from the floor. After palpating all of the spinous processes, nine spherical reflective markers (B&L Engineering,Tustin, CA) were attached to the spinous processes of T1, T3, T5, T7, T9, T12, L3, L5 and S2 using hypo-allergenic double sided tape (Figure 7.1). A single digital still camera (Sony Cyber-shot Model No DSC S950; Sony Corporation, Tokyo, Japan) was positioned on a flat and level surface at a height of 72 cm from the floor and parallel to and 145 cm from, the edge of the plinth for the prone tasks, and at a height of 75 cm and 145 cm away from the chair for the sitting tasks. In this way the camera was approximately centred on the reflective marker at T9.

Photographs were acquired at rest and at the end of range for extension in each of three prone tasks (P1, P2 and P3). Each subject was instructed in the tasks to be performed. In the case of the prone tasks they were instructed to keep their eyes on an object positioned in line of sight on the floor under the face hole in the plinth. This ensured that they kept their head down and did not hyper-extend their neck. In sitting the subjects were asked to keep their eyes on an instruction notice positioned in their line of sight when their head was kept in a neutral position. Each task was practiced prior to being photographed. The subjects were instructed to extend as far as possible and hold that position for 5 seconds. They rested for 2 minutes between each task.

Although the prone tasks were performed first, the order in which they were performed was randomised. After the six prone lying photographs were taken, the subjects were positioned in sitting. Three photographs were taken in sitting, one at rest and one at the end of range of extension for both S1 and S2. As above, the order was randomised. All of the photographs were taken with a flash to illuminate the retro-reflective markers.

7.2.2.4. The AutoCAD measurement method

The photographs were copied into a computer-aided drawing program (AutoCAD 2005 Version N63.0; Autodesk, Inc. CA, USA) which allowed for accurate post-processing of the photographs in order to acquire the angular data. The angles were acquired in the following way. The centroid of each ball was determined with an AutoCAD circle drawing function. This enabled the accurate location of construction lines to be drawn connecting each adjacent centroid. The angles subtended by each of the adjacent lines were measured using the AutoCAD angle measurement function. The angles obtained therefore reflected the inter-segmental angle at ‘T3’ (T1-T5), ‘T5’ (T3-T7), ‘T7’ (T5-T9), ‘T9’ (T7-T12), ‘T12’ (T9-L3), ‘L3’ (T12 – L5) and ‘L5’ (L3-S2) (Figure 7.2). Thus, although labelled as single levels, each ‘level’ covers a number of motion segments. The convention used dictated that the ‘extension’ angle measured was always that which was anterior to the spinal curve (Figure 7.2) so that if the angle increased, the degree of extension was greater.

After being analysed by the author, the photograph sets of five subjects were randomly selected and re-measured by an independent assessor. This was done in order to assess the accuracy and repeatability of the AutoCAD technique for deriving segmental angles from photographs in this way.

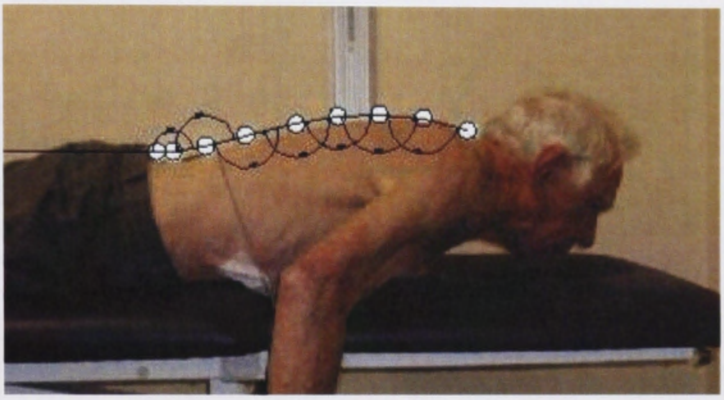


Figure 7.2. The AutoCAD method of measuring the angles in prone. The extension angle was the angle measured under the curve.

Note. The lumbar angles appear to be over the curve but were subtracted from 360°.

7.2.2.5. Statistical Analysis

The statistical software used was Stata version 10.1 (Statacorp, Texas USA) and Genstat Release 13.1 (VSN International, Hemel Hempstead, UK).

The dependent variables examined in this study were maximum segmental extension angle (maximum angle) and also the change in angle between the resting position and the fully extended position (angle difference). The summary data for each group were expressed as mean and standard errors (mean (SE)). A split-plot ANOVA model with age group and gender as between-subject effects, and position (at rest and in extension) and segment (T3, T5, T7, T9, T12, L3 and L5), as within-subject effects, was used to compare both maximum angle and angle difference data. *Post hoc* analyses of all significant comparisons were performed using least significant difference values (LSDs). Differences were considered significant when $p < 0.05$.

Agreement between the two observers in the inter-observer reliability study was assessed using an intra-class correlation co-efficient ($ICC_{1,2}$).

7.2.3. Results

7.2.3.1. Summary of results

A detailed description of the results with numerical values is presented below (Table 7.1 and Table 7.2), but a brief overview is presented here to aid the reader.

The AutoCAD measurement method demonstrated high levels of inter-observer reliability.

The younger group extended significantly more in prone than the older group and most of the difference was at T7 and T12. The females extended most at L3 and L5 and males most at T9 andT12.

The thoracic spine extended more during sitting with retraction but this was only significant at T7 and T12. The lumbar spine was significantly more extended in prone than it was in sitting. The upper thoracic spine flexed relative to the rest position during sitting with retraction only.

7.2.3.2. The inter-observer reliability of the AutoCAD technique

Subjects 8,12,15,17 and 20 were the subjects whose photographs were randomly selected for independent assessment in order to test the accuracy of the AutoCAD technique. The measurements made by observer 2 correlated very highly with those of observer 1 ($ICC_{1,2} = 0.96$; $p < 0.001$).

7.2.3.3. The effects of age and gender

Overall, the younger group demonstrated significantly more segmental movement than the older group (mean angle difference 4.4° ± 2.7° vs 2.7° ± 4.2°; $p = 0.006$) and a significantly larger mean maximum angle (183.0° ± 14.0° vs 180.1° ± 11.8°; $p = 0.009$), but this difference was only seen in the prone tasks.

When analysed by segment (

Table 7.1), the older women extended most at L3 and the older men extended most at T9 and significantly less at L3 than any other gender/age sub-groups ($p < 0.001$).

7.2.3.4. The effect of the extension task on thoracic and lumbar inter-segmental movement

A summary of the inter-segmental maximum angle and angle differences for each of the five extension tasks is provided in Table 7.2.

Overall, the prone extension tasks resulted in significantly more extension at L3 and L5 than the sitting tasks ($p < 0.001$). However, the P1 task differed in that the mean angle difference at L3 was significantly smaller than for any other task ($p < 0.001$).

In the upper thoracic segments (T3 and T5) the mean angle differences were significantly smaller in sitting than they were in prone ($p < 0.001$). The angle differences for the S2 task at T3 and T5 were negative indicating that the thoracic spine became less extended at these levels relative to the resting position.

At T7 (apex of the curve) both the maximum angle and angle difference were greatest for the S2 task. However, only the angle difference reached significance when compared with P1 ($p < 0.001$).

At T9 there were no significant differences between the tasks. However, S2 resulted in the highest maximum angles and P2 and P3 resulted in the highest angle differences.

At T12 both the mean maximum angle and the mean angle difference were both significantly greater for the S2 task ($p < 0.001$).

At L3 the mean maximum angles for all the prone tasks were significantly greater than those for the sitting tasks ($p < 0.001$). However, the angle differences were similar for all the tasks except P1 which was significantly lower ($p < 0.001$).

At L5 the mean maximum angles were significantly greater for the prone tasks than they were for the sitting tasks. Further, the angular differences during all prone extension tasks were significantly greater than for S2 ($p < 0.001$) but not S1.

7.2.4. Discussion

7.2.4.1. Overview of main findings

The main aim of this study was to determine which extension task results in the most inter-segmental extension of the thoracic spine. The results indicate that the thoracic spine extended more in sitting with scapular retraction (S2) than during any other extension task, but this only reached significance at T7 and T12. In contrast, the lumbar spine was significantly more extended during the prone extension tasks than it was during the sitting tasks. The younger group extended significantly more than the older group during the prone extension tasks only and this difference in extension occurred primarily at T12. Both the older males and females extended less at the apex of the thoracic curve (T7) than the younger group but this only reached significance in the older males.

7.2.4.2. Ranges

In this study the minimum and maximum range of thoracic inter-segmental movement was -3.9° (min at T3) and 7.6° (max at T12). These values were smaller than the 7.1° to 9.7° range which was reported in a previous *in vivo* study which used electromagnetic tracking to measure thoracic inter-segmental extension [49]. However, the studies were different in three ways.

Table 7.1

The mean maximum angle and angle differences by age category and gender.

Agecat	<30*				>70			
	Female		Male		Female		Male	
	Max	Diff	Max	Diff	Max	Diff	Max	Diff
T3 (T1-5)	169.3 (1.3)	0.7 (1.1)	169.7 (1.2) (	1.8 (1.2)	169.7 (1.3)	1.1 (1.3)	171.2 (1.1)	1.6 (0.9)
T5 (T3-7)	171.9 (1.4)	2.3 (0.8)	171.8 (1.4)	2.2 (1.1)	172.9 (0.9)	2.0 (0.6)	170.3 (0.9)	1.8 (0.4)
T7 (T5-9)	175.2 (1.6)	5.1 (1.3)	175.2 (1.6)	6.1 (0.7)	173.2 (0.7)	2.5 (0.4)	169.6 (0.7)§	1.8 (0.5)
T9 (T7-12)	177.5 (1.3)	4.4 (1.1)	181.8 (1.0)	5.8 (0.8)	175.3 (1.3)	4.0 (0.7)	178.8 (1.0)	4.6 (0.7)
T12 (T9-L3)	190.9 (1.4) †‡	2.7 (1.1)	193.4 (1.0) †‡	8.4 (0.9)‖	185.6 (1.1)	3.4 (0.5)	180.9 (1.0)	2.9 (0.7)
L3 (T12-L5)	196.3 (1.8)	5.9 (1.1)	193.8 (1.5)	5.6 (1.0)	200.8 (1.5)	6.0 (0.8)	189.2 (1.6)	2.0 (1.2)
L5 (L3 – horizontal)	204.5 (5.2)	10.5 (4.5) ¶	187.6 (0.8)	0.8 (0.9)	189.0 (2.2)	1.3 (1.0)	196.6 (1.7)	3.1 (1.1)

Note. All angles represented are in degrees (mean (SE)). The data represents mean angles for all of the extension tasks, i.e. collapsed data. Age categories (Agecat) are in years.

* significantly greater angle difference than the older group ($p = 0.006$).

† significantly larger mean maximum angle than the older group at T12 ($p = 0.009$)

‡ significantly greater mean maximum extension angle than the older group at T12 ($p < 0.001$).

§ significantly lower maximum extension angle at T7 than all other gender/age groups ($p < 0.001$).

‖ significantly greater angle difference than all other gender/age groups at T12 ($p < 0.001$).

¶ significantly greater angle difference than all other gender/age groups at L5 ($p < 0.001$).

Table 7.2

The maximum inter-segmental extension angles (max) and the mean differences between rest and extension (diff) for the five extension tasks.

Position	T3 (T1-5)		T5 (T3-7)		T7 (T5-9)		T9 (T7-12)		T12 (T9-L3)		L3 (T12-L5)		L5 (L3-S2)	
	max	diff	max	diff	max	diff	max	diff	max	diff	max	diff	max	diff
P1	172.3	3.5	174.4	3.2	172.3	2.0	176.3	2.5	184.9	1.6	196.3	1.9	198.7	5.4
	(1.1)	(0.1)	(1.0)	(0.5)	(0.8)	(0.6)	(1.3)	(0.8)	(1.3)	(0.9)	(2.0)	(1.1)	(4.5)	(3.7)
P2	172.6	2.6	172.5	3.2	173.0	4.3	178.8	6.9	185.8	3.5	198.4	5.4	198.2	5.1
	(1.3)	(1.2)	(1.1)	(0.6)	(0.6)	(0.5)	(1.3)	(0.8)	(1.4)	(0.8)	(2.0)	(1.1)	(4.2)	(3.2)
P3	172.7	3.25	172.4	3.4	172.6	3.6	178.0	6.5	186.6	3.9	197.4	5.8	198.7	6.1
	(1.1)	(1.0)	(1.1)	(0.8)	(0.8)	(0.7)	(1.0)	(0.6)	(1.5)	(1.1)	(2.1)	(1.3)	(4.3)	(3.2)
S1	170.2	0.8	170.9	1.4	173.6	3.8	178.6	3.0	189.4	5.4	191.3	5.6	189	1.9
	(1.2)	(0.7)	(1.2)	(0.5)	(1.5)	(1.1)	(1.5)	(0.9)	(1.6)	(0.8)	(1.7)	(1.1)	(1.5)	(0.9)
S2	165.3	-3.9	168.4	-0.8	175.7	5.9*	180.4	4.7	191.8	7.6	191.8	5.9	187.8	0.8
	(1.4)	(1.3)	(1.3)	(0.9)	(2.0)	(1.4)	(1.7)	(0.9)	(2.1)	(1.4)	(1.8)	(1.2)	(1.5)	(1.1)

Note. All angles represented are in degrees (mean (SE)). In sitting the extension angles at the upper thoracic spine actually decreased which is to be expected because translation of the head posteriorly results in the upper thoracic spine becoming relatively more flexed.

* significantly different to P1 ($p < 0.001$).

First, our subjects extended from a relaxed neutral sitting position to an upright position, whereas the subjects in the study by Willems and Jull (1996) were instructed to arch their backs maximally in a sitting position. Second, half of the subjects used in this study were over 70 years of age whereas the subjects in the Willems and Jull study were aged 18 to 24 years. Finally, the method used in this study to measure inter-segmental movement involved measuring overlapping spinal sections in order to evaluate the movement of the segment at the centre of each section. Willems and Jull also measured the spine in sections, but as blocks which did not overlap (T1-T4, T4-T8 and T8–T12). The advantage of our method was that it was potentially more sensitive to change at individual levels. The studies are therefore not really comparable. Overall, however, a general increase in extension range from cephalad to caudad was detected in this study which is consistent with the findings of previous studies [49, 56, 111].

7.2.4.3. Effect of scapula retraction

In the sitting position, retracting the scapulae (S2) resulted in consistently greater extension from T7 to T12. It also resulted in significantly more extension at the apex of the thoracic curve (T7) than the P1 extension task. It is not clear why retraction of the scapulae results in more thoracic extension although scapulae protraction has been reported to be associated with a increased kyphosis [581] and retraction of the scapulae is a strategy which is used in postural exercises for the treatment of thoracic kyphosis [582]. Retracting the scapulae activates the middle fibres of trapezius and also the rhomboid muscles [581]. Previous research indicates that contraction of the middle fibres of trapezius may stabilise the cranial end of the thoracic spine [155] thereby enabling the thoracic erector spinae to extend the thoracic spine more effectively (2.3.11.6 and 2.4.3.1). Another possibility is that by moving the shoulder girdle more posteriorly, the flexion moment acting on the thoracic spine is reduced because the weight of the arms is moved posteriorly and therefore closer to the centre of rotation in the sagittal plane. It is possible that both of these mechanisms may contribute to the increased inter-segmental movement that was observed during extension with scapular retraction, but further research is needed to clarify this question.

7.2.4.4. Flexion of the upper thoracic spine

The upper thoracic spine apparently flexed during sitting with retraction compared to the resting position. Close inspection of the photographs (Figure 7.3) revealed that in sitting extension with scapula retraction (S2) causes posterior translation of the head over the cervical spine so that the cervical spine and upper cervical spine become very slightly more flexed. This 'chin tuck' is indicative of the activation of the deep neck flexors which are needed for the facilitation of optimal cervico-thoracic postural form and whose activation is encouraged in the clinical management of neck pain [550]. Therefore this 'flexion' of the upper thoracic spine during S2 is, in fact, an indication of better postural form than was present in any of the other extension tasks.

7.2.4.5. Age and gender differences

In this study, the main differences between the older and younger groups occurred at T7 and T12. Age-related changes in the vertebrae, inter-vertebral discs and other soft tissues combined with age-related decline in muscular strength have all been documented as reasons for the increased stiffness which occurs in older people (2.5). At T7 both the older men and women were less extended, the older men significantly so. Since T7 is the apex of the thoracic curve [249], loss of extension at this segment would significantly affect the degree of kyphosis. Therefore, decreased extension range at this segment is consistent with the literature describing increases in kyphotic angle with increasing age (2.2.2). Over the whole cohort the task which resulted in the most extension at T7 was S2. However, the older men demonstrated better, if limited, extension at T7 during the P2 task.

The young men demonstrated the greatest extension ranges at T12. In contrast, the older men extended most at T9 while the young females extended most at L5 and the older females at L3. This tendency for females to extend more at the lumbar levels has been observed in studies which have examined sitting strategies in men and women. Women tend to sit more upright with increased lumbar extension and increased anterior pelvic tilt while men are more likely to assume a flexed lumbar posture with less anterior pelvic tilt and lumbar extension [83, 583].

The observation that the older subjects extended most at levels which were more superior to their younger counterparts may reflect mechanically-induced degeneration of the inferior segment due to overuse in youth or, perhaps, a compensation for increased stiffness in the thoracic segments due to age-related changes. Once again, further research is required to clarify this question.

7.2.4.6. Limitations

Limitations of this study include the small sample size, the use of photography for kinematic analysis and the use of spinal regions instead of spinal segments. While the sample was small, it was large enough to answer the principal question i.e. which extension task results in the most thoracic inter-segmental movement? Using skin markers for photographic measurement has been shown in previous studies to be reliable (Table 2.6) and in this study the measurements were made on the same subject at the same time thereby minimising the potential for repositioning errors. The differences between the amount of skin movement between different subjects was not considered and this may have affected the measurements in terms of angular differences, but skin markers are commonly used to measure thoracic spine movement [49, 344, 368]. The findings reported in chapter 3 (3.3.3) indicated that the skin surface measurements over approximately 9 segments were a mean 3.5° ± 6.9° greater than the skeletal measurements [584]. With this in mind, the maximum angle measurements reported are potentially larger than those which would be measured at the spine itself, but the angular differences should not have been affected. The technique used to measure the inter-segmental angles was time-consuming but our reliability study indicated that it was robust. The segmental movement described, although labelled as corresponding to a particular level was actually a composite of four motion segments with the T12 ‘segment’ actually including six motion segments (T9 to L3). The motion reported is therefore only an indication of the motion of the spinal region with the level cited at its centre. Previous *in vivo* studies of spinal movement using skin markers have commonly employed a strategy such as this because the markers would be too close together otherwise [49, 344, 368].

The cohort used for this study contained two specific age groups, one under 30 years and one over 70 years. Most biomechanical studies are conducted using young males [428, 566, 585] and the results therefore do not necessarily apply either to older people or to females. The results of this study indicated that age and gender do matter which supports the case for caution when extrapolating data from unmatched age and gender cohorts. The results for the S1 task may have been enhanced by more specific postural-correction instruction. In a study which aimed to investigate the difference between the "sit up straight" command and therapist-guided extension in sitting, more specific instruction was found to result in better facilitation of key postural muscles [550]. By specifically instructing the subjects in how to sit up straight with an upright pelvic position and a neutral spinal lumbo-pelvic position it is possible that the thoracic extension angles achieved may have been better. However, had this instruction been used the same instruction would have applied to the S2 position thereby nullifying the differences. Nevertheless an examination of the effect of such a strategy would be of interest.

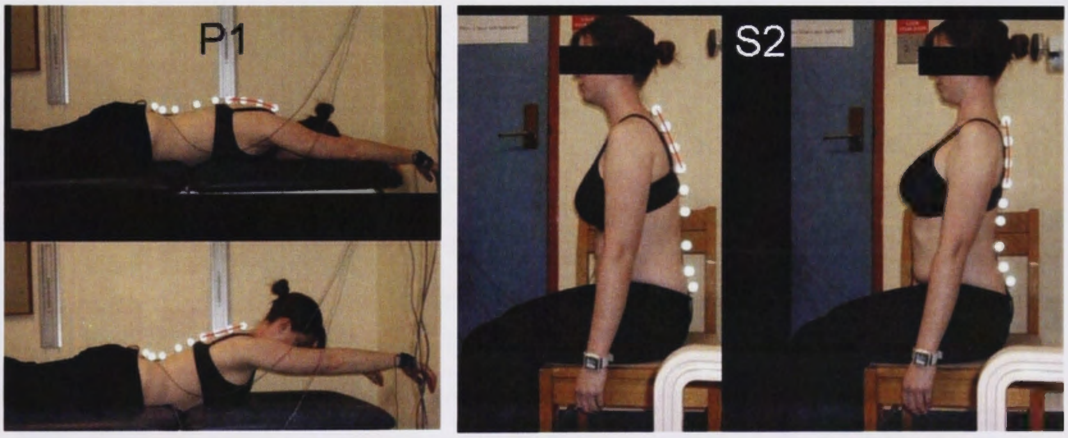


Figure 7.3. The upper thoracic segments during extension in prone (P1) and during sitting with retraction (S2). The red lines are included to illustrate how in Prone (P1) extension results in the upper thoracic spine becoming less flexed, while in sitting (S2) extension causes the segments to become relatively more flexed as the neck retracts and balances the head over the thoracic spine.

7.2.5. Conclusions

The results of this study support the hypothesis that extension exercises performed in prone lying result in less thoracic spine extension than is achieved during sitting with scapular retraction. The results for the older men indicate that this group may respond better to the P2 task but the number of subjects in this subgroup was too small to be conclusive. Women appear to extend more at the lumbar levels while men extend more in the lower thoracic spine. Sitting with scapular retraction, when performed as described in this study, appears to result in a better upper thoracic spine posture than any of the other extension tasks.

7.3. Comparison of the thoracic and lumbar erector spinae contributions to prone and sitting extension – an sEMG and force measurement study.

7.3.1. Introduction

Previous research has indicated that increased back extensor strength is associated with lower angles of thoracic curvature and is therefore potentially protective of hyperkyphosis [564]. However, the findings of a number of studies do not support this theory [8, 283]. In a study which evaluated the effect of a two year programme of resisted prone extension exercises in a cohort of post-menopausal women, kyphotic angle was found to be unchanged compared to a control group [10]. The question which arises from these findings is whether extension from prone is an effective exercise for the thoracic erector spinae (TES). The results of the surface electromyography (sEMG) pilot study described in chapter 5, suggested that the lumbar erector spinae (LES) were more active during prone extension exercises than they were during extension in sitting. Although the results of the pilot study also indicated that the TES were more active in sitting extension with scapula retraction, the ultrasound study described in chapter 6 revealed that the sEMG signal from the thoracic recording site would, in fact, have originated from the more superficial trapezius muscle. The relative activity of the TES during prone and sitting extension exercises is therefore still uncertain.

Prone extension exercises are not only employed as exercises for the thoracic spine, but are also used to strengthen the lumbar erector spinae and multifidus muscles [567]. However, it has been suggested that the compression forces generated in the lumbar spine during prone extension exercises may prove detrimental to people with low back dysfunction [586]. Callaghan calculated that compression forces of approximately 4000N could occur in the lumbar spine during the 'superman' exercise which involves lifting both the arms and legs in prone (Figure 5.2 (AUG)) [566]. This is consistent with the lumbar spine being the fulcrum for spinal extension in prone and suggests that the thoracic spine may not be.

It is hypothesised, therefore, that the TES may be recruited more effectively in the sitting position. However, this is difficult to test directly with sEMG because of the overlying superficial muscles (as explained in chapter 6). An alternative method of comparing the contribution of the TES is to compare the moment generated during an extension task as a function of how much the LES contributed to the production of that moment. The resulting ratio would reflect the contribution of the unmeasured TES activity, thereby serving as an analog for TES activity. It is hypothesized that the extension moment generated in sitting will not be different to that measured in prone and that, in keeping with the results of chapter 5, the LES activity will be larger during the prone extension tasks. Consequently, it is hypothesized that the ratio of extension moment to LES activity will be greater during the sitting extension tasks and greatest during extension with scapular retraction.

Spinal stability and control is enhanced by co-contracting the trunk muscles [218, 587]. The compression of the motion segments which is achieved by co-contraction is believed to ensure that there is a more even force distribution across all the segments, thus avoiding stress concentrations at vulnerable points [587]. In addition, increasing the overall stiffness of the segment enables it to resist bending forces [218]. As has been previously discussed (chapter 2, 0), the degree of thoracic kyphosis has been reported to be higher in athletic adolescents compared to their sedentary peers [210]. By co-contracting during extension exercises, the abdominal muscles (being trunk flexors), would potentially inhibit thoracic extension. Therefore, determining whether levels of abdominal activity are different in extension in the prone or sitting positions is of interest.

The primary aim of this study was to assess the relative contribution of the TES and LES during extension from prone compared to extension from sitting. The secondary aim was to assess the relative activity of the abdominal muscles during prone and sitting extension tasks. Because the majority of studies which have used sEMG to investigate spinal biomechanics have measured young subjects [218, 566, 567, 588], a final aim was to determine the effect of age on the relative recruitment of the trunk muscles during the different extension exercises.

7.3.2. Method

7.3.2.1. Subjects

The subjects for this study were the same as those used in chapter 6 (Table 6.2) and the same exclusion criteria and ethical approvals applied.

7.3.2.2. Positioning the dynamometer

The spinous processes were palpated and marked by the author. A FEG was calibrated and attached to the skin centred on the T6/T7 inter-spinous space as described in chapter 3 (3.2.2). The subjects were instructed to sit up as straight as possible on a wooden chair which has been previously described (5.2.3). The minimum angle displayed by the FEG in upright sitting was recorded. All of the subsequent isometric resisted myometry measurements were made with the thoracic spine at this angle. To this end, a hand-held dynamometer, mounted on an adjustable wall-mounted bracket (5.2.3), was positioned with the transducer head just superior to the superior angles of the scapulae (which was approximately over T3) while the back was held at the minimum angle described above. The dynamometer position on the wall mounting was recorded so that the exact position could be reproduced later. The subject was then positioned prone on the plinth with their face in a cut-out section for comfort. They were asked to extend until the FEG angle displayed was the same as that recorded for upright sitting.

The dynamometer was then positioned above the superior angle of the scapulae (approximately T3) and the position was marked in the wall mounting. In both sitting and prone lying the transducer head was positioned flat against the back with its long axis oriented horizontally. In prone this required both the mounting bracket and the transducer head to be rotated through 90° (Figure 7.4).

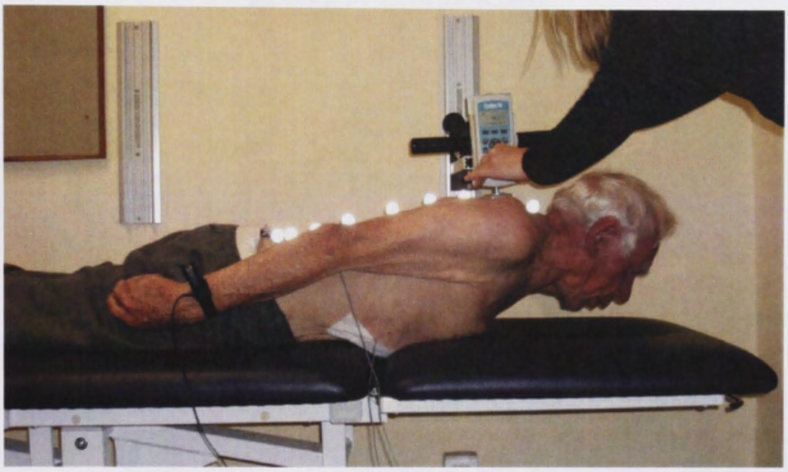


Figure 7.4 The position of the dynamometer with the subject in prone lying

7.3.2.3. Attaching the sEMG electrodes

The FEG was removed and the skin surface was cleaned with warm water prior to attaching two surface EMG SX230 preamplifiers with built in dual electrodes (Biometrics Ltd, Cwmfelinfach, UK). One preamplifier was positioned over, and in line with the muscle fibres of the right external oblique muscle (EO) just below the most inferior rib angle along a line connecting the most inferior point on the ribs with the contralateral pubic tubercle [589] (Figure 7.5). The EO was chosen to represent the abdominal muscles because it is superficial and lateral so that the subjects would not be required to lie directly on the sensor when prone. The second preamplifier was positioned over the right LES muscles 2 cm lateral to the L4 spinous process (Figure 5.1). The subjects were asked to extend in prone with their arms above their heads (P1) and hold for 5 seconds in order to establish the correct channel sensitivity for each of the muscles (0-3mV). The preamplifiers were calibrated to zero prior to being attached to the subject. A ground strap (Biometrics

R206 was attached to subject so that the ground electrode contacted the styloid process over the right wrist. The sampling rate for each recording was 1000 Hz.

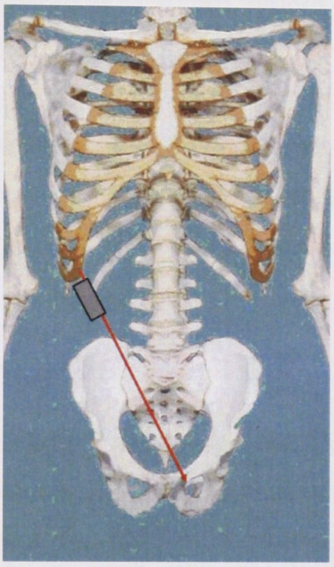


Figure 7.5 The position of the sEMG recording electodes (grey box) over the right external oblique muscle. The red arrow shows the direction of the muscle fibres.

7.3.2.4. The 'active' extension tasks

Five extension tasks were performed in this study. Three of these tasks were performed in prone lying and two were performed in sitting. The five tasks are shown in Figure 2. P1, P2 and P3 (the prone extension tasks) have been described previously in chapter 6. The sitting tasks were: extension in sitting without scapular retraction (S1), and extension in sitting with scapular retraction (S2).

7.3.2.5. The resisted extension tasks

After the three sEMG recordings were made for the three prone positions the dynamometer was attached to the wall and placed in the pre-determined position (above). The extension tasks were repeated with the subjects instructed to push into the pad as hard as they could for 5 seconds. This was repeated twice more and the maximum of the three force measurements was recorded. The subjects were given 60 seconds rest between each of the three attempts.

The distance from the dynamometer position (T3) to L3 was measured. This distance was used to calculate the moment exerted by the extensors in the prone position (below). In the same way, the resisted sitting measurements followed the active extension tasks. During the seated extension tasks the subjects were asked to look at a sign at eye level to prevent them from hyper-extending their necks. They rested their extended legs on a 10 cm high wooden block with instructions not to push through their heels. Heel pressure was manually monitored by the researchers and any attempts where force was exerted through the heels were re-measured.

7.3.2.6. Processing the EMG data

In order to obtain meaningful amplitude values, two filters were applied to the raw EMG waveform. First, the waveform was corrected to be centred on 0 mV using the 'add for zero' filter. Second, the RMS (root mean square) filter was applied with a moving average of 20ms. The RMS filter rectifies and averages the waveform. The presence of interference from line frequency pick up was assessed for each recording using the power spectrum graphing facility in the Biometrics software. No harmonic peaks were detected after filtering. The maximum amplitude for both the external oblique and the LES muscles for each task were measured. In the case of the resisted extension tasks, the maximum amplitude was that which was the highest over all three recordings. The maximum amplitudes were normalised by identifying the maximum amplitude recorded over all ten tasks (five active and five resisted) for each muscle in each individual subject. The amplitudes were then divided by the maximum value so that each was expressed as a proportion of the maximum amplitude recorded.

7.3.2.7. Calculating moments from force data

The moments developed during extension in all five positions were calculated from the maximum force data, the kinematic photographs, and published anthropometric data [590]. The kinematic study (7.2) indicated that, over all the positions, the largest mean extension range took place at L3 (Table 7.3) so this was the position selected as the centre of rotation for all the moment calculations. Consequently, the distance between T3 (the transducer head position) and L3 (the nominated axis of rotation) was measured for each subject in both prone and in sitting. Images of P1, P2 and P3 at rest were loaded into a computer-aided drawing program (AutoCAD 2005 Version N63.0; Autodesk, Inc. CA, USA) and the distances from T3, T7, the tragus of the ear, the elbow and the neck (just below the chin) to L3 were measured. The AutoCAD measurements were converted into centimetres by using a conversion factor calculated by dividing the 'autoCAD' T3 to L3 distance by the known (measured) T3 to L3 distance.

A free body diagram was constructed for prone extension (Figure 7.6.) and sitting extension (Figure 7.7). Simple equations to calculate the moment developed about L3 in each of the task conditions were constructed (Figure 7.6 and Figure 7.7).

In order to calculate the ratio of moment to LES activity, the moments were 'normalised' in the same way as were the EMG data by dividing each moment by the maximum moment measured for each subject over all five extension tasks.

7.3.2.8. Reliability

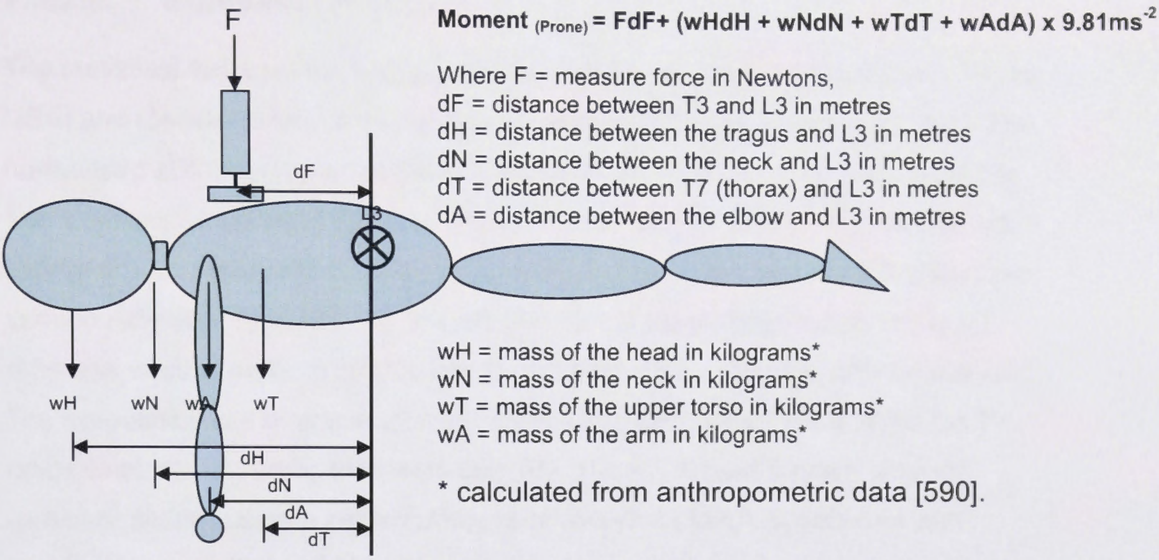
The reliability of the moment calculations for the prone positions was tested by selecting five subjects at random on which the measurements were made by two independent assessors.

Table 7.3

Change in extension angle for each segment and position from the kinematic study (7.2).

	T3	T5	T7	T9	T12	L3	L5
P1	3.5	3.2	2.0	2.5	1.6	1.9	5.4
P2	2.6	3.2	4.3	6.9	3.5	5.4	5.1
P3	3.3	3.4	3.6	6.5	3.9	5.8	6.1
S1	0.8	1.4	3.8	3.0	5.4	5.6	1.9
S2	-4.1	-0.7	6.1	4.7	7.5	5.7	0.8
Mean Prone	3.1	3.2	3.3	5.3	3.0	4.4	5.5
Mean Sitting	-1.7	0.4	5.0	3.8	6.4	5.6	1.4
Mean Both	**1.2**	**2.1**	**3.9**	**4.7**	**4.4**	**4.9**	**3.8**

Note. Although the largest mean angle difference for prone was at L5 and for sitting was at T12, overall the largest mean was at L3 so this position was selected as the centre of rotation for the moment calculations.



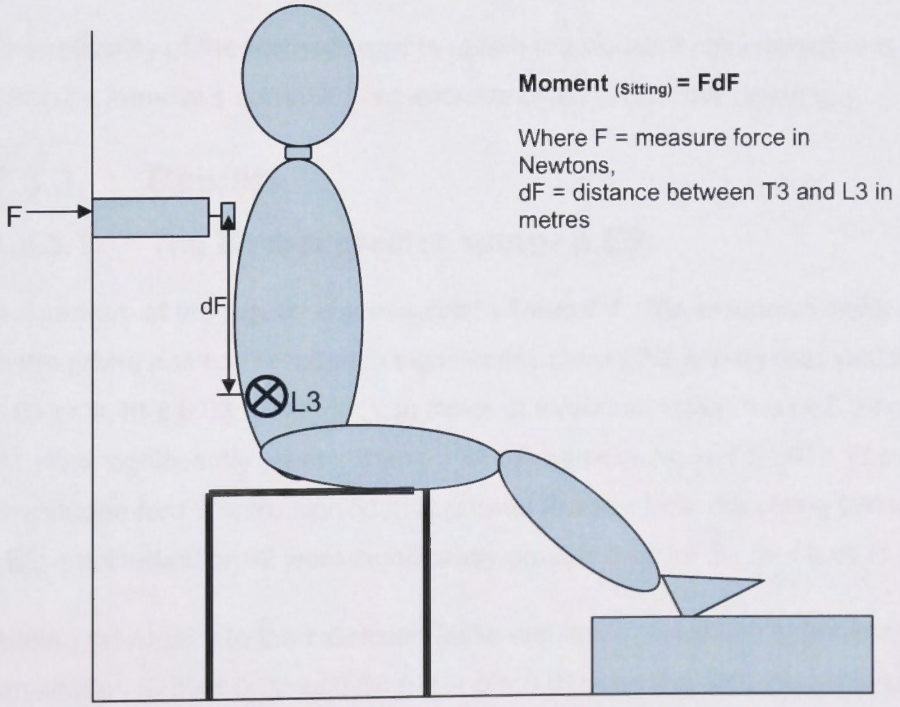
$$\textbf{Moment}_{(Prone)} = FdF + (wHdH + wNdN + wTdT + wAdA) \times 9.81\,ms^{-2}$$

Where F = measure force in Newtons,
dF = distance between T3 and L3 in metres
dH = distance between the tragus and L3 in metres
dN = distance between the neck and L3 in metres
dT = distance between T7 (thorax) and L3 in metres
dA = distance between the elbow and L3 in metres

wH = mass of the head in kilograms*
wN = mass of the neck in kilograms*
wT = mass of the upper torso in kilograms*
wA = mass of the arm in kilograms*

* calculated from anthropometric data [590].

Figure 7.6 Free body diagram and equation for calculating the moment at L3 during P2.



$$\textbf{Moment}_{(Sitting)} = FdF$$

Where F = measure force in Newtons,
dF = distance between T3 and L3 in metres

Figure 7.7 Free body diagram and equation for calculating the moment at L3 during sitting.

7.3.2.9. Statistical Analysis

The statistical software packages used were Stata version 10.1 (Statacorp, Texas USA) and Genstat Release 13.1 (VSN International, Hemel Hempstead, UK). The normalised sEMG signal amplitudes are presented as the mean ± standard error. The log transformation of the ratio of the normalised moments to the normalised lumbar ES amplitudes (T:L) was calculated to compare the thoracic ES activation in each extension task (P1, P2, P3, S1 and S2). A log transformation of the T:L ratio was used in order to reduce the asymmetry of the ratio data prior to analysis. The normalised signal amplitudes for the thoracic ES, lumbar ES and the log T:L ratios were compared by extension task (P1, P2, P3, S1and S2) and position (prone or sitting) using a nested analysis of variance (ANOVA) with task and position nested within subject. *Post hoc* analyses of all significant comparisons were performed using least significant difference values (LSDs). Differences were considered significant when $p < 0.05$.

The reliability of the method used to obtain the moment calculations was assessed using an intraclass correlation co-efficient ($ICC_{1,2}$) (x15 per assessor).

7.3.3. Results

7.3.3.1. The lumbar erector spinae (LES)

A summary of the results is presented in Table 7.4. The extension tasks performed in the prone position resulted in significantly more LES activity that in sitting (0.81 ± 0.01 vs 0.40 ± 0.03; $p < 0.001$). In terms of individual tasks, the LES amplitudes for P1 were significantly greater than for all the other tasks ($p < 0.001$). The LES amplitudes for P2 were significantly greater than for both the sitting tasks; and the LES amplitudes for S2 were significantly greater than for S1 ($p < 0.001$).

Adding resistance to the extension tasks resulted in significantly greater LES amplitudes (0.69 ± 0.20 vs 0.58 ± 0.3; $p = 0.01$) and this was more marked in sitting than it was in prone (sitting: 0.49 ± 0.03 vs 0.31 ± 0.04; prone: 0.84 ± 0.02 vs 0.77 ± 0.02).

There were no significant differences in LES amplitude between males and females (0.65 ± 0.28 vs 0.63 ± 0.28 respectively) across all of the tasks. However, the older females had significantly greater LES amplitudes in the sitting tasks (0.52 ± 0.05) than both the young females (0.30 ± 0.06) and the young males (0.36 ± 0.06) but not the older males (0.41 ± 0.04; p=0.029).

Although not significant at the 0.05 level, there was a trend for LES activity to be greater in the older group than it was in the younger group (0.66 ± 0.02 vs 0.61 ± 0.03; p= 0.06).

7.3.3.2. The external obliques (EO)

The mean EO amplitude for P1 (combined active and resisted) was significantly greater than for any of the other tasks ($p < 0.001$) but there were no significant differences between any of the other tasks (Table 7.4).

The older group recorded significantly greater normalised EO amplitudes than the younger group across all positions and tasks (0.61 ± 0.02 vs 0.49 ± 0.03; p = 0.007) (Figure 7.8).

The sitting position resulted in significantly lower EO amplitudes than those recorded in the prone position across all subjects, (0.46 ± 0.03 vs 0.61 ± 0.02; p = 0.006).

There were no significant differences between genders in terms of EO amplitudes in any position or task, (females = 0.57 ± 0.27; males = 0.53 ± 0.26).

Resistance to the extension tasks resulted in significantly greater EO amplitudes (0.61 ± 0.03 vs 0.49 ± 0.03; p = 0.01).

Table 7.4

Summary of mean normalised sEMG amplitudes, mean moments, mean normalised moments and mean log ratio values by task.

Task	EO	LES	Moment	Nmoment	Log ratio
P1	0.75 ± 0.04*	0.87 ± 0.02*	106.66 ± 11.16	0.85 ± 0.05	-0.13 ± 0.13
P2	0.53 ± 0.03	0.79 ± 0.03**	109.87 ± 10.51	0.88 ± 0.03	0.06 ± 0.06
P3	0.54 ± 0.04	0.75 ± 0.03**	100.65 ± 12.73	0.79 ± 0.05	0.09 ± 0.09
S1	0.43 ± 0.04	0.37 ± 0.03	93.20 ± 8.96	0.75 ± 0.04	0.52 ± 0.11
S2	0.49 ± 0.04	0.43 ± 0.04‡	102.27 ± 9.90	0.84 ± 0.05	0.50 ± 0.12

Note. Mean ± SE. Abbreviations: EO = right normalised external oblique signal amplitudes; LES = right normalised lumbar erector spinae signal amplitudes; Moment = moments calculated at L3 (Nm); Nmoment = normalised moments; and Log ratio = log of the ratio of normalised moment to normalised lumbar ES signal amplitude.

* significantly greater than all other task values ($p < 0.001$); ** significantly greater than S1 and S2 ($p < 0.001$); ‡ significantly greater than S1 ($p < 0.001$).

7.3.3.3. Reliability of the moment calculations

The $ICC_{1,2}$ for the results measured by assessor 1 compared to assessor 2 was 0.99 ($p < 0.0001$).

7.3.3.4. The moments

The moments calculated for all five extension tasks are presented in Figure 7.9. The moment generated during S1 was significantly less than P1 and P2 ($p < 0.05$). Otherwise, there were no significant differences between the tasks.

The mean moment developed by the younger group was significantly greater than that of the older group (114.44 ± 7.0 Nm vs 90.60 ± 6.10 Nm; $p < 0.0001$). However, when the moments were normalised across the tasks there was no difference due to age.

The moments generated by the males was significantly greater than by the females (127.03 ± 7.80 Nm vs 77.72 ± 2.03 Nm; $p < 0.0001$) however after normalisation, there was no significant difference.

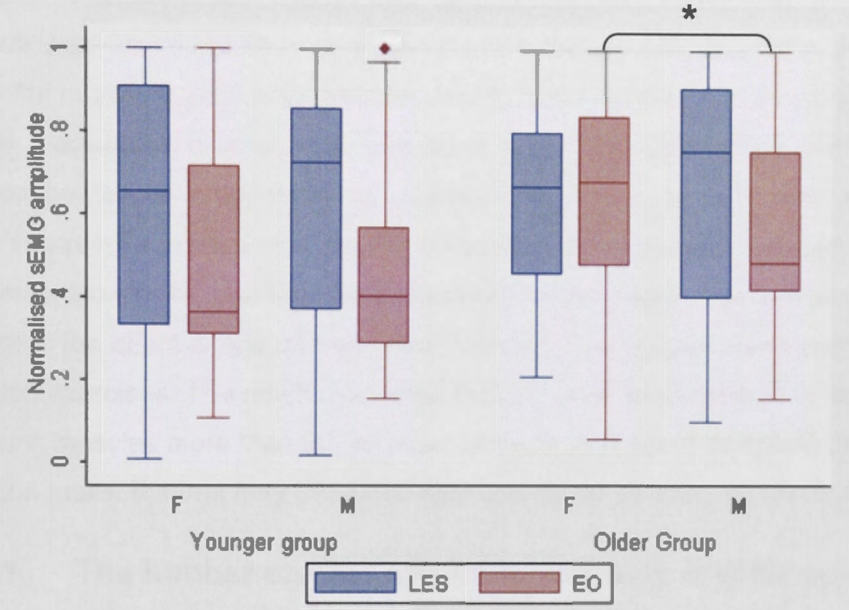


Figure 7.8 The normalised sEMG amplitude of the lumbar erector spinae (LES) and external oblique muscle (EO) (combined prone and sitting extension tasks) by age category and gender. The older subjects had significantly greater normalised EO amplitudes than the younger subjects.

Note. The figures presented are all expressed as the ratio of RMS EMG amplitude during the task to the maximum EMG amplitude recorded over all of the tasks.

* significantly greater than the younger group ($p<0.007$).

7.3.3.5. The normalised moment to LES ratios

The log ratio of normalised moment to normalised LES amplitude was significantly higher for the sitting tasks than for the prone tasks (0.51 ± 0.08 vs 0.003 ± 0.06; $p < 0.001$) (Table 7.4 and Figure 7.10).

7.3.4. Discussion

The primary aim of this study was to assess the relative contributions of the thoracic and lumbar erector spinae muscles (TES and LES) during prone and sitting extension exercises. The findings of this study indicate that the LES contribute significantly more to prone extension than to sitting extension, even though the moments produced are comparable. It is therefore concluded that the TES are more active in sitting than they are in prone. The second aim was to compare the degree of activity in the external oblique muscles (EO) in prone and sitting. The results indicate that the EO were significantly more active during the prone extension tasks than they were during the sitting tasks. The final aim was to investigate the effect of age on trunk muscle activity during prone and sitting extension exercises. The results indicated that the older subjects had to activate their trunk muscles more than the younger subjects in order to complete the extension tasks, but that they produced significantly smaller extension moments.

7.3.4.1. The lumbar erector spinae vs thoracic erector spinae

The LES were significantly more active during the prone extension tasks than they were in sitting, particularly during P1. This supports the findings of the pilot study (chapter 5) and indicates that during prone extension the LES were much more active than they were in sitting.

Surface EMG is commonly used to quantify the amount of force produced by muscles [567]. There is a strong linear relationship between the force production and sEMG amplitude in both the LES and EO muscles [591]. Because it was not possible to measure the activity in the TES directly, the contributions of the TES were represented by a ratio of the moment produced during the extension tasks to the normalised LES sEMG amplitude. When compared as a ratio (log ratio moment/LES), the sitting task ratios were significantly larger than they were for the prone tasks. This indicates that the LES contributed significantly less to the extension moment developed in sitting than they did in prone. Since the moment developed in sitting with retraction was the same as that developed in prone, it is reasonable to assume that the TES were responsible for the majority of the moment developed during sitting that was not developed by the LES

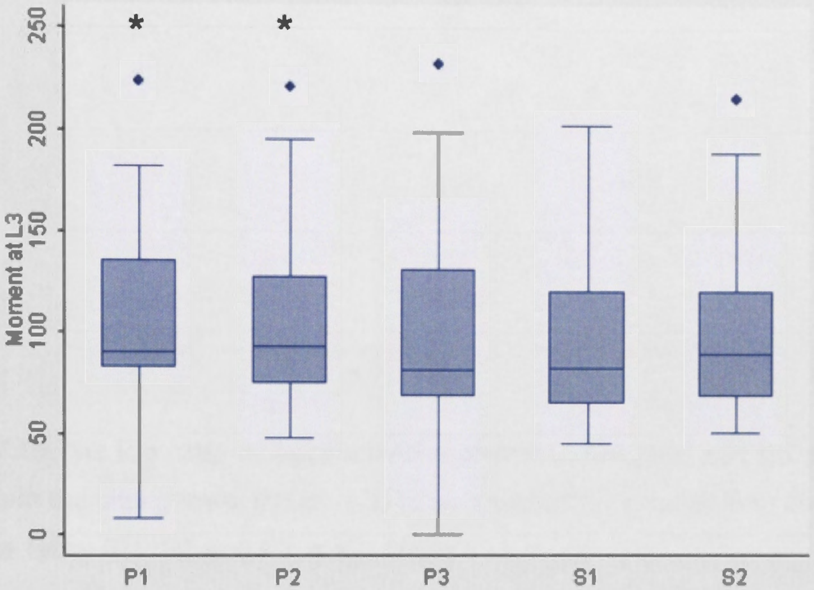


Figure 7.9 Moments generated at L3 calculated from the force data and anthropometric measurements. P1 and P2 moments were significantly greater than S1 only. The moments were otherwise not significantly different.

Note. * significantly greater than S1 ($p < 0.05$).

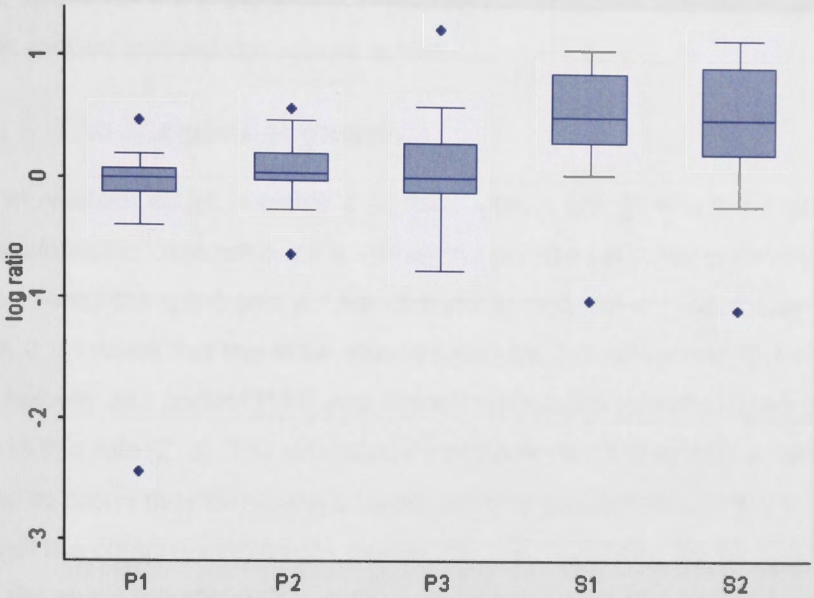


Figure 7.10 The log ratio of normalised moment to normalised LES activity. The ratio in the sitting tasks (S1 and S2) was significantly greater than it was in the prone tasks (P1, P2 and P3; $p < 0.0001$).

Note. The '0' on a log_ratio scale corresponds to a ratio of 1.

7.3.4.2. The effect of retracting the scapula (S1 vs S2)

Although there was no significant difference between the EO amplitudes recorded during S1 compared to S2, the difference in LES activity was significant ($p < 0.001$) with scapular retraction (S2) resulting in greater LES amplitudes. In addition, the mean moment developed during S2 was slightly larger than that developed during S1 (102.30 ± 9.90 Nm vs 93.20 ± 9.00Nm) implying that retracting the scapulae was an effective way of increasing extension power. It is difficult to explain why retraction of the scapulae resulted in increased LES activity and extension moment. It is possible that the increased stiffness of the spine which results from contracting the middle fibres of trapezius (2.4.3.1 and 7.2.4.3) may enable the TES and LES to act more effectively. Another explanation may be that the pressure exerted by the contracting trapezius and rhomboid muscles might improve the efficiency of the erector spinae contraction by way of 'hydraulic amplification'

(2.4.3.6). Whatever the explanation, retracting the scapulae resulted in enhanced extension ranges and erector spinae activity.

7.3.4.3. The abdominal muscles

The EO were more active in prone than they were in sitting. The fact that the abdominal muscles contract at all is somewhat perplexing bearing in mind that the task is to extend the spine and yet the abdominal muscles are essentially flexors. However, it is known that the trunk muscles preload the spine prior to movement to achieve stability and control [111] and the EO have been reported to be particularly involved in this role [218]. The discrepancy between the EO activity in sitting compared to prone may be due to a lesser need to preload the trunk in sitting because of the compression forces exerted by gravity. These forces potentially stabilise the spine thereby reducing the need for so much abdominal 'bracing'.

7.3.4.4. The role of the latissimus dorsi

The EO amplitudes were greater for the P1 task. This task required the subjects to extend their trunk in prone while keeping their arms above their heads. P1 was subjectively the most difficult of the extension tasks and the one in which the most LES activity was recorded. The increased activity of the EO would theoretically have made the execution of this activity even more difficult for the extensors. One explanation for the relative increase in EO activity in P1 may be that the lever arm was longer resulting in the need for a greater degree of spinal pre-loading and therefore more EO activity. Another explanation may lie in the role of the latissimus dorsi muscle (2.3.11.7). During P1 the latissimus dorsi muscle is essentially disabled because its antagonists must act to maintain the arms above the head. In P2 and P3 however, the latissimus dorsi is noticeably active (Figure 7.11). The fibre direction of the latissimus dorsi in prone suggests that it may have a role in flexing the upper trunk relative to the lower trunk. It is proposed that, in prone, the abdominal muscles and the latissimus dorsi muscles act as spinal compressors stabilising the thoracic spine into an arch as was previously discussed (2.4.3.7). This theory of the spine relying on its arches for stability was first proposed by Aspden [190]. By stabilising the thoracic spine into an arch, this potentially complex multi-segmental system (think of an articulated wooden snake) would be simplified, allowing the LES, assisted by the gluteal and hamstring muscles via the thoraco-lumbar fascia (2.4.3.5) to lever the thorax into extension by extending at the lumbar spine. In sitting however, it is proposed that the abdominal muscles are primarily involved in stablising the lumbar spine so as to allow the TES to extend the thoracic spine more effectively. Indeed, the kinematic study (7.2) revealed that the sitting with scapular retraction task (S2) was more effective in terms of achieving extension at the thoracic apex than any of the prone lying positions.

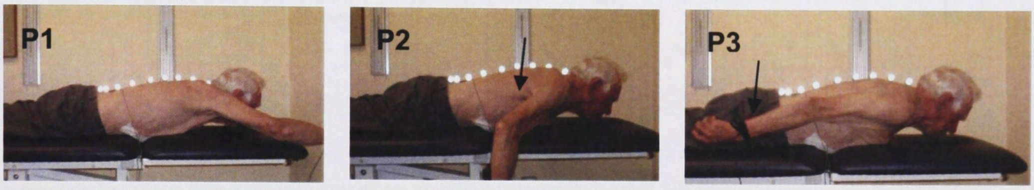


Figure 7.11. Subject 1 performing the P1, P2 and P3 tasks. The arrow in P2 points to the latissimus dorsi muscle contracting. In P3 the arrow points out the internal rotation of the shoulder indicating latissimus dorsi contraction.

Fixing the thoracic spine into an arch would theoretically require significant anterior muscle action unless the latissimus dorsi with its extensive insertion into the spine (2.3.11.7 and Figure 2.10) is recruited. The oblique action of the latissimus dorsi potentially exerts a stablising force on the thoracic spine while not directly opposing the LES, thereby reducing the need for the abdominal muscles to be so active. In addition, the latissimus dorsi would stabilise the lumbar spine and potentially increase the efficiency of the LES by hydraulic amplification (2.4.3.6). Hence, in P2 and P3, where the latissimus dorsi muscles were able to assist, the EO were less active and so were the LES even though the lumbar extension ranges were greater (7.2.3.4).

7.3.4.5. The effect of age

The younger group was different to the older group in a number of important ways. First, the mean normalised sEMG amplitudes were higher in the older subjects, although significance was only reached for the EO. The implication is that the older subjects were working about 10% harder than the younger subjects in order to perform the extension tasks. The relatively greater EO effort may be related to the increased stiffness of the thoracic spine in the older subjects (7.2.4.5). It is possible that the older subjects more readily utilised the strategy of fixing their spine into an arch and levering themselves from the lumbar spine with very little contribution from the TES which were required to act over flexed and relatively immobile segments. The results of the kinematic study (7.2) support this theory in that the older subjects, particularly the older men, demonstrated very little inter-segmental movement in their mid-thoracic spine.

In the sitting tasks, the older subjects demonstrated greater LES`amplitudes than the younger group, but this was only significant in the older women. The most likely reason for the increased activity is that the older subjects used an increased amount of lumbar extension in an attempt to compensate for the increased stiffness of their thoracic segments. However, if this were true, the older men, who were shown to be stiffer in the thoracic spine than the females (7.2), would presumably have demonstrated greater LES activation than the females. However, women have been shown to sit in a more upright position with increased anterior pelvic tilt compared to men, who tend to sit in amore slumped position [83, 583]. The older women may therefore have been driven to attempt to achieve more extension than the men which led to relatively greater LES activity.

The moments were significantly smaller in the older group which is consistent with the literature relating to age-related declines in muscle strength (2.5.1.4).

7.3.4.6. The potential compression loads

The LES and EO amplitudes were significantly smaller during extension in sitting than they were during prone extension and therefore extension exercises in sitting may be safer from the perspective of reducing potentially damaging lumbar compression forces, than prone extension exercises. Callaghan, Gunning et al. (1998) calculated that the extension forces produced during extension from the prone position can be as high as 4000N. Because the lumbar spine is hyper-extended, these high compression loads are transferred to the zygapophyseal joints and have the potential to crush the interspinous ligament [586]. Although the moments developed by females and older subjects were shown to be lower than in the young males which Callaghan, Gunning et al. (1998) measured [566]; the potential for damage should not be overlooked.

7.3.4.7. Limitations.

The main aim of this study was to compare the relative contributions of the TES and LES muscles during extension from prone and sitting. The main limitation, therefore, is that the TES could not be directly recorded with sEMG because of the overlying trapezius muscle (chapter 6). The method that was devised to overcome this problem relies on a number of assumptions. First, it was assumed that the TES must have been more active in sitting because the contribution of the LES was reduced yet the extension moments were similar. There are, however, some other possible explanations. The gluteal and hamstring muscles are powerful hip extensors which potentially contribute to the lumbar extension moment due to their connections with the thoraco-lumbar fascia (2.4.3.5). The decreased LES amplitudes in sitting could therefore have been the result of the gluteal and hamstring muscles being in a more mechanically advantageous position. The potential contribution of the gluteii and hamstrings was reduced by: positioning the subjects' feet on a block in front of the body, specifically instructing the subjects not to push through the feet, and manually monitoring the pressure through the subjects' heels during the task. Therefore, we believe that the gluteal and hamstring muscles were very unlikely to have made a significant contribution. However, a future study might include recording the degree of gluteal and hamstring activity during the extension tasks and/or monitoring the pressure being exerted through the feet.

The EO activity was normalised using the maximum amplitude from the five extension tasks. Whereas the LES amplitude was indeed the maximum since it was recorded from the maximal voluntary isometric contraction (MVIC), the EO amplitude was not recorded from the maximal effort for that muscle. The values for the normalised EO amplitudes therefore would have differed if the MVIC had been used to normalise the data. For example, Callaghan, Gunning et al. (1998) [566]

reported mean EO amplitudes of between 0.03 and 0.07 of MVIC during their prone extension measurements whereas the normalised EO amplitudes reported in this study were between 0.43 and 0.75. Because the relationship is linear, however, normalisation with submaximal efforts is a legitimate strategy [440, 442] but it does not permit comparison with data from other studies.

The free body diagram moment calculations used in this study were very simple and did not involve the complex modelling algorithms used in other studies [566]. However, granted that we were only doing internal comparisons, it was appropriate to use a simple model. Anthropometric data are, of course, only an estimation based on subject height and weight but assumptions like these are widely used in the field of biomechanics [592, 593]. Similarly, modelling the thorax and trunk as a rigid segment is naïve, especially in view of the kinematic data presented in 7.2 which clearly shows significant thoracic mobility during extension. Once again, making assumptions like these is accepted biomechanical practice [594] and the same assumptions were applied to all of the subjects. Finally, it was assumed that the centre of rotation for all the subjects during all five of the extension tasks was at L3. Therefore, all of the moment arm measurements were made from this point. As was discussed in 7.2, the maximum extension rotation varied with age and gender. L3 was, however, the point at which the mean maximum rotation occurred (Table 7.3) and it was therefore nominated as the centre of rotation for the study.

7.3.5. Conclusions

This is the first study to compare the effectiveness of prone and sitting extension tasks with respect to recruitment of the TES and LES. The results indicate that the LES are more active during prone extension exercises in spite of the fact that the extension moments are similar. Retraction of the scapulae increases the extension moment achieved in sitting as well as the LES and external oblique amplitudes. There is some evidence to indicate that the trunk muscles may act to fix the thoracic spine into an arch configuration during prone extension exercises, thereby potentially explaining the reduction in thoracic inter-segmental extension shown in 7.2. The latissimus dorsi is implicated in this role as well as the EO. The results therefore indicate that extension from prone is primarily a lumbar extension exercise and extension in sitting is a better thoracic extension exercise.

7.4. Conclusions to chapter 7

This chapter has included a description of two studies, both of which aimed to explore the efficacy of sitting as an alternative position in which to strengthen and test the thoracic extensors with a view to reducing thoracic hyperkyphosis. The results support the hypothesis that sitting with scapular retraction is a more effective thoracic spine extension exercise, both in terms of inter-segmental movement and muscle activation.

Both the kinematic and the sEMG studies supported the hypothesis that prone extension exercises are primarily lumbar spine extension exercises. This appears to be particularly the case in older people where thoracic movement is limited and muscle strength is diminished. The relative increase in External Oblique (EO) activation during extension in prone, particularly in the older group, points to the possibility that the strategy used to extend the trunk in prone may involve fixing the thoracic spine into an arch (increased kyphosis) and raising this stable structure with the powerful lumbar extensors. The concept of increasing the thoracic kyphosis to stabilise the region has been discussed in chapter 2 (0). It is therefore possible that by prescribing extension exercises in prone the thoracic kyphosis could actually be increased.

This is the first time that the issue of whether prone or sitting extension exercises are more effective for the thoracic spine has been investigated. Although the literature has not specifically addressed this issue, there are still several studies whose results support our findings. First, Callaghan, Gunning et al. (1998) investigated lumbar extension exercises and determined that prone extension with the arms above the head resulted in very large levels of lumbar erector spinae activity [566]. Second, Miyokoshi et al. (2005) measured thoracic and lumbar angles and back extensor strength in prone in older women and found that there was no correlation between back extensor strength and the thoracic kyphosis angle whereas extensor strength was significantly related to the lumbar angle

[283]. Finally, in an intervention study which aimed to decrease thoracic kyphosis angles in hyperkyphotic women, Katzman et al (2007) [8] did not detect a correlation between back extensor strength and thoracic angle. They concluded that their measurement methods were probably measuring the lumbar erector spinae muscles.

The results of the two studies presented in this chapter support the superiority of seated extension with scapular retraction as a thoracic extension exercise and therefore seated extension with scapula retraction will be used for the randomised controlled trial described in chapter 9. Whether the seated extension test used to measure the force exerted by the erector spinae muscles in this study, has test-retest reliability, is addressed in the next chapter.

Chapter 8.

The Reliability of the Seated Extension Test

8.1. Introduction

Prone lying is the most commonly cited position for measuring the strength of the thoracic spine extensors [10, 12, 74, 80, 95, 283, 322, 348, 423, 480, 490, 595, 596]. Although this position has been reported to be reliable with a coefficient of variation of just 2.3% [423], prone lying is a difficult position for many elderly people or disabled people to assume [11]. Also, prone potentially imposes significant extension on the spine and forces the subject to develop an extensor moment in the weaker inner range. In people who are older or disabled, extending from prone can be difficult and so the possibility of a significant floor effect is increased when measuring from this position.

In chapters 5 and 7 the effectiveness of using sitting as an alternative position to test and strengthen the thoracic extensors was explored. The results of these studies indicated that sitting with scapula retraction resulted in better extension range of movement in the thoracic spine and greater extension moments than prone extension and just sitting erect without scapula retraction. Prone extension was more difficult than sitting extension, especially for older subjects who achieved reduced ranges of movement in this position compared to sitting.

The objective measurement of muscle strength is achieved by using a myometer. A description of myometry and a discussion of the literature is included in Chapter 2 (2.7.1). As has been previously discussed, the most common methodology used to measure thoracic back extensor strength is extension from prone lying [10, 423, 597]. However, sitting extension has also been used in some previous studies [8, 11, 424]. The seated dynamometers which have been used are generally large commercially available units which have a generic 'back extension' mode whose centre of rotation favours the measurement of lumbar extension. However one study by Mika et al. (2005) tailored their testing apparatus to the thoracic spine by positioning the dynamometer transducer head at the level of the superior border of the scapulae in order to better target the thoracic extensors [11]. This dynamometer transducer head position was used in the studies described in chapter 7 to resist extension in sitting using a wall mounted hand-held dynamometer. However, this application has not been tested for reliability so, although we have established that sitting with retraction is an superior method of recruiting the thoracic extensors, the level of test-retest reliability needs to be established before it can be used for the randomised controlled trial.

The aim of this study therefore, was to evaluate the test-retest reliability of measuring extension in sitting with scapula retraction using a wall mounted dynamometer positioned at the level of the superior border of the scapulae. A secondary aim was to verify that extending the thoracic spine with scapular retraction resulted in greater force generation than extending without retraction.

8.2. Method

8.2.1. Subjects

Ten adult subjects were recruited by word of mouth and posters mounted in the Canberra Hospital. The participants consisted of 5 females and 5 males. The demographics for the subjects are shown in Table 8.1.

Table 8.1
Subject demographics (n=10)

	N	*Age*	*Height*	*Weight*	BMI
Males	5	46.4 (26-74)	175.5 (165.5-186)	80.4 (64-96)	26 (23 - 31)
Females	5	42.2 (26-69)	163.4 (154-173)	63.2 (58-74)	24 (22-27)

Note: Data is presented as the mean (range). Units for height are centimeters and weight is in kilograms. BMI = Body Mass Index.

8.2.2. Procedure

A detailed explanation of the test procedure used can be found in chapter 5 (5.2.3). Each measurement was made three times with a 60 second rest between each 5 second test. The best of the three measurements was recorded.

The myometry measurements were made 7 days apart, at approximately the same time of day, by the same assessor.

Exclusion criteria included previous significant spinal problems such as; fracture, surgery, spinal disease, thoracotomy, pregnancy; neuropathy or myopathy. All subjects gave informed consent. Ethics approval for this study was granted by the ACT Health Human Research Ethics Committee and the Australian National University Human Research Ethics Committee.

8.2.3. Statistical analysis

The statistics used to describe the data included mean values and standard errors (mean ± SE).

The repeatability of the measurement technique was calculated by comparing the time 1 and time 2 tests using an intraclass correlation coefficient ($ICC_{2,1}$) (two way mixed effect model, for absolute agreement with a correlation of average measures). The extension and the extension with retraction conditions were tested separately.

A two-tailed paired t-test was used to compare the forces generated with and without scapular retraction. For this analysis the time 1 and time 2 data were combined.

The minimal difference needed to show a meaningful change in myometry measurements using this seated myometry technique, was calculated from the equation $MD = SEm \times 1.96 \times \sqrt{2}$ where SEm is the standard error of measurement ($SEm = SD\sqrt{1-ICC}$) [327].

Differences were considered significant when $p < 0.05$.

8.3. Results

The test-retest reliability of the myometry measurements for extension only and extension with retraction were excellent ($ICC_{2,1} = 0.95$ (95% CI 0.79-0.99) and $ICC_{2,1} = 0.96$ (95% CI 0.83 – 0.99) respectively). The minimal differences needed to detect a real difference in force generated between measurements (MD) were 24.4N for extension only and 20.7N for extension with retraction.

The mean absolute differences between the time 1 and time 2 measurements for extension and extension with retraction were 10.3N± 12.6N and 5.8N ± 10.7N respectively (

Table **8.2**).

Extension with retraction resulted in the generation of significantly greater forces than extension alone (293N ± 25.3N vs 249.7N ± 22.8N; p=0.002) (

Table **8.2** and Figure 8.1).

Table 8.2

Thoracic extension force measurements with and without scapular retraction measured one week apart

Subject	Extension only		Extension with Retraction	
	T1	T2	T1	T2
1	195	206.4	274.2	266.2
2	162.8	172.6	187	201.6
3	406.6	369.4	568	509.8
4	80.6	143.6	206.4	201.6
5	111.2	204.8	233.8	274.2
6	159.6	201.6	195.2	208
7	303.2	272.6	314.6	369.4
8	387.2	398.6	427.6	330.8
9	322.6	296.4	334	306.6
10	363	311.4	355	376

Note:.All measurements represent the maximum of three measurements. T1=time 1 and T2 = time 2. All measurements are in Newtons (N). Extension with scapular retraction resulted in significantly greater forces generated (p = 0.002).

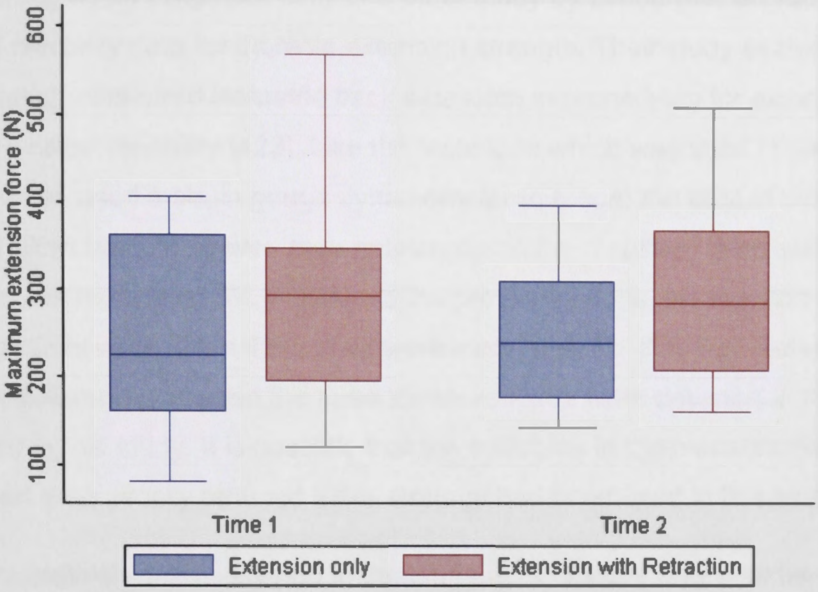


Figure 8.1 Time 1 and Time 2 measurements of maximum force generated for extension only, and extension with scapular retraction.

Note. Extension with retraction resulted in significantly higher forces than extension alone (p=0.002).

8.4. Discussion

The aim of this experiment was to evaluate the test-retest reliability of a novel method of assessing the strength of the thoracic back extensors using a wall mounted dynamometer. A secondary aim was to verify that scapular retraction enhanced the amount of force generated during thoracic extension. The $ICC_{2,1}$ of 0.95 for both extension with and without scapular retraction indicated that both tasks had high reliability and repeatability. The minimal difference needed to be certain of a meaningful change was less for extension with retraction. Extension with retraction also resulted in significantly higher force production.

The results of this study showed that the test-retest reliability for extension in sitting with or without scapular retraction was very high, however the data was quite variable. The reliability of thoracic back extensor strength measurement has not been thoroughly investigated. Only one other study by Limburg et al (1991) has reported reliability data for thoracic extension strength. Their study evaluated a system which measured isometric back extension in prone lying for external validity and test – retest reliability [423]. Like the technique which was used in this study, Limburg et al. used a strain gauge dynamometer to record the best of three maximal effort trials. However, they only accepted the results of the trial if the final effort was not more than 5% different to the previous efforts. No mention was made of what actions were taken if the trials were more than 5% different. Between 16% and 21% difference between the three measurements were detected in the cohort measured in this study. It is possible that the variability in the measurements could have been dramatically reduced if this strategy had been used in this study.

The comparatively small variation in the Limberg et al.study may also be due to the potential floor effects for prone extension tasks. In the sEMG/force study reported in chapter 7 (7.3) some of the older subjects were unable to extend sufficiently in prone to record any force on the dynamometer. This phenomenon would limit the variability of the measurements between time 1 and 2 considerably and may have contributed to the fact that the coefficient of variation between time 1 and time 2 measures in the Limburg study was just 2.3% [423].

In this study, the minimum meaningful difference (MD) for myometry in sitting was reported. These data has not been previously reported. Dvir and Keating (2001) reported standard error data for seated extension using an isokinetic dynamometer [598]. The standard errors were much higher for their males than were found in this study but the data for the females was similar. They did not, however, report MD data. The standard errors were relatively high, which is a reflection of the variability in the data. However, by knowing the MD a threshold can be set over which force data must increase in order that it can be interpreted as a meaningful change [327]. The Limberg et al. study did not report an MD either.

The primary limitation of this study is that it involved only ten subjects. However, Limberg et al. [423] derived their data from a group of just 13 subjects and their findings have been widely accepted as justification for the prone measurement method. Also, the age range was well distributed with both genders being evenly represented. The problems associated with the seated position in terms of minimizing the contribution of the legs, has been discussed previously (7.3.4.7). Although it is possible that the relative increase in variability in sitting is due to unwanted lower limb involvement, the calculation of an MD compensates for this variability and potentially makes the seated test more sensitive to changes in thoracic back extension strength than the prone lying test which is the current standard.

In conclusion, this study aimed to evaluate the test-retest reliability of the seated extension test for measuring thoracic extension. The test has been shown to be highly reliable for extension with and without scapular retraction. But extension with scapular retraction was less variable and more effective in terms of the development of extension force, than extension without scapular retraction. The minimal difference needed to show a meaningful change for sitting with retraction was 20.7N. These data and information will be used for the design and execution of the randomised controlled trial of two interventions for reducing the kyphotic angle of the thoracic spine which is described in the following chapter.

Chapter 9.

A Randomised Controlled Trial of Postural Re-education and Progressive Resisted Strengthening for Hyperkyphosis

9.1. Introduction

Thoracic kyphosis has been reported to increase by between 6% and 11% per decade over the age of 55 years with or without evidence of osteoporosis [13]. The consequences of hyperkyphosis have been discussed previously (2.2.6) but include increased mortality, decreased physical dysfunction, reduced psychological and emotional well being and falls. Therapeutic strategies which prevent or reduce hyperkyphosis of the thoracic spine are therefore important to the maintenance of good health throughout adult life. Recent research has revealed that age-related thoracic hyperkyphosis, which had previously been thought to be due to osteoporotic vertebral collapse, is more often due to disc degeneration and subsequent bony remodelling (2.5.1.3). However, the increased anterior compression forces which result from increased kyphosis may contribute significantly to osteoporotic vertebral compression fractures [195]. Information about the efficacy of therapeutic strategies which aim to reduce thoracic kyphosis in adults is therefore important to the many health professionals who work with this population, particularly physiotherapists.

There have been a number of studies which have sought to evaluate the effectiveness of different treatment programmes which aim to reduce hyperkyphosis [8-10, 96-98, 100, 452, 482, 549]. These studies have typically involved post-menopausal women for whom hyperkyphosis is a significant and sometimes urgent problem. Some of these studies have shown that the programme of treatment being evaluated has resulted in significant improvement, while others have not.

Of the RCTs conducted in this area (see

Table **2.7**) the most relevant is a study by Greendale et al. (2009). This trial aimed to evaluate the efficacy of yoga for reducing hyperkyphosis [9]. In the study, the control group attended monthly luncheon seminars while the intervention group attended yoga sessions three times a week for 24 weeks. Kyphosis was measured with a Debrunner kyphometer and a flexicurve (2.6.3.1 and 2.6.3.2). The kyphometer measurements which showed a reduction in kyphosis of 3° in the yoga group and 1.3° the control group were not significant. However, the angle derived from the flexicurve, which showed a 0.93°reduction in the yoga group compared to a 0.82° reduction in the control group, was statistically significant.

Although it was not randomised or controlled, another study stands out, because it reported much greater and highly significant improvements in kyphosis as a result of the therapeutic programme administered. Katzman et al. (2007) reported reductions in thoracic angle of 5 and 6 degrees (Debrunner kyphometer) and a 21% increase in back extensor strength after a 12 week multidimensional exercise programme [8]. The subjects were 21 women with a mean age of 72 years and a kyphosis greater than 50°. Nineteen of these women were tested one year later and were found to have maintained their improved postural control and strength.

Other studies which have evaluated prone back extension exercises [10], a multidimensional exercise programme [96] and pilates exercises [452] have not detected significant changes in thoracic angle. One suggestion is that the extent to which thoracic angle decreases is dependent on the extent of the pre-existing kyphosis [10, 96] but this has not been proven. In both of the studies which showed a significant reduction in thoracic angle, the intervention involved a number of strategies i.e. stretching, strengthening and education. Therefore, although it has been shown that a reduction in thoracic angle is possible in older people, what is not known is whether particular strategies are differentially more effective than others.

The results of a survey of Australian physiotherapists (chapter 4) showed that the three most commonly used strategies for reducing kyphosis were postural re-education, stretching and back extensor strengthening. Back extensor strengthening as a treatment for thoracic kyphosis has received a lot of attention and support in the literature [12, 95, 221, 580] but, although an association has been reported, good evidence in support of its efficacy as a treatment has not been forthcoming. This has been discussed in detail in chapter 2 (2.9.2.2) Postural re-education has been included in many of the intervention programmes which have been evaluated to date (2.9.2.1) but it has yet to be evaluated in isolation.

Stroke is a condition which primarily affects older adults and can result in severe physical disability (stroke is discussed in detail in chapter 2 (2.10)). Stroke affects the trunk as well as the limbs [15] and good trunk control has been shown to be related to better ability with activities of daily living [515]. Trunk muscle weakness has also been shown to be related to poor balance in people with stroke [14] and impairment of trunk control has been reported to be evident in non-acute and chronic stroke patients [599]. Clinical studies have shown that trunk extension, in particular, is significantly weaker in people with stroke than it is in non stroke-affected people [513].

Lack of trunk extensor strength leads to slumped or kyphotic posture and lack of trunk extension in sitting and standing [600]. Treatment for trunk weakness in people with stroke most commonly involves facilitating motor re-learning by assisting patients to re-learn functional tasks such as rolling, moving from lying to sitting, sitting and reaching, moving from sitting to standing, standing and walking etc [517]. Other methods include facilitation techniques where the therapist aims to induce normal automatic movement control through trunk manipulation techniques [601]. In both of these methods trunk extension is encouraged when performing the therapeutic activities and so they could be considered to be analogous to postural re-education. Trunk strengthening, in terms of resisted exercises, has not been studied in people with stroke, although recent reports have been supportive of the use of strengthening for improving overall function in stroke [519-521].

Strengthening can take many forms but a progressive resisted programme has been reported to be the most effective because it promotes a gradual increase in stress upon the target muscles which results in adaptive changes [602]. In the non-athlete, a programme which involves 4 sets of 10 repetitions three times a week using a resistance of 60% of 1RM (the maximum weight able to be lifted) has been reported to be the most effective [602].

In older people the thoracic spine becomes stiffer [3, 7, 44] and degenerative disc disease is common. As mentioned previously, degenerative disc disease is related to increased thoracic kyphosis. The most likely cause of degenerative disc disease is reduced nutrition which, in turn, is profoundly reduced by decreased movement frequency (2.5.1.3). Therefore, the maintenance of adequate movement frequency is crucial to the maintenance of disc health and possibly the prevention of kyphosis. Thoracic movement frequency has not been previously reported and so there is no data on what is normal and whether it is related to kyphotic angle. The flexible electrogoniometer (FEG) is an instrument which is capable of measuring both kyphotic angle [584] and the frequency of angular change in the area over which it is applied [409].

This study was designed to try to identify the relative efficacy of back extensor strengthening and postural re-education at reducing thoracic kyphosis angle in adults with and without stroke. The relative effect of a stretching programme, however, has not been addressed at this time.

9.1.1. Study aims

In accordance with the points above the study aims were:-

1. To assess the effects of strengthening and postural re-education on thoracic kyphosis, physical performance, pain and spinal movement frequency in non-osteoporotic people over the age of 40 with and without stroke.

2. To explore the effects of gender, age, body mass index (BMI) and stroke, on the changes in the thoracic angle, physical function, back extensor strength (BES) and spinal movement frequency as a result of participating in 12 weeks of strengthening and/or postural re-education.

3. To investigate the behaviour of the thoracic spine in terms of movement frequency in the sagittal and coronal planes (flexion/extension and side flexion) during normal unconstrained activities.

4. To explore the relationship between back extensor strength (BES) and thoracic angle in a non-osteoporotic population both in terms of baseline values and the change over the 12 week intervention period.

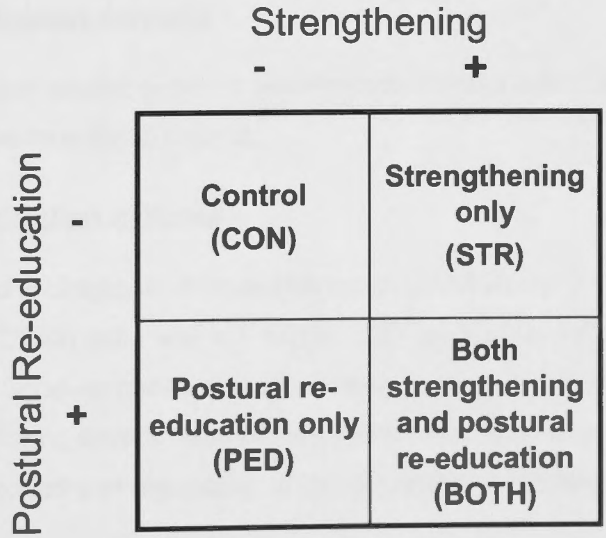
5. To explore the relationship between thoracic angle at baseline and the degree of change in angle at 12 weeks.

6. To examine the distribution and attributes of Kendall's postural classification types in terms of thoracic kyphosis angle within the study population.

9.2. Methods

9.2.1. RCT design

A 2 X 2 factorial design was used for this RCT (Figure 9.1). This design was used in order that the effect of each of two interventions strengthening and postural re-education, as well as the combination of the two, could be assessed. The advantage of this design is that the effect of each intervention could be examined by comparing the groups where they are present (see '+' column and row in Figure 9.1) with the groups where they are not (see '-' in Figure 9.1). as well as the interaction of both. The 2 X 2 factorial design was applied to both a normal and a stroke cohort. Therefore each subject was randomly allocated to one of four intervention groups: strengthening (STR), postural re-education only (PED), both strengthening and postural re-education (BOTH) and control which received neither (CON).



Postural Re-education	Strengthening -	Strengthening +
-	**Control (CON)**	**Strengthening only (STR)**
+	**Postural re-education only (PED)**	**Both strengthening and postural re-education (BOTH)**

Figure 9.1 The 2 X 2 factorial design with 2 factors: strengthening and postural re-education.

9.2.2. Selection of the study population

The subjects were recruited by invitation following a radio interview, a newspaper article, talks at stroke clubs and elderly care facilities, advertisement in community newsletters and free newspapers, posters and word of mouth within the Australian Capital Territory. Stroke subjects were also notified of the trial by direct mailing from four consultant neurologists. All of the subjects were invited to contact the trial co-ordinator by telephone or email. The subjects were screened for eligibility over the telephone following the guidelines listed below. If eligible, the trial was explained in detail. All suitable and interested potential subjects were sent an information pack with written information about the trial, a copy of the consent form, and the study questionnaires (appendix B). The subjects were asked to complete the study questionnaires in the week preceding their assessment.

All subjects gave informed consent. Ethics approval for this study was granted by the ACT Health Human Research Ethics Committee (ETH.6/05.395) and the Australian National University Human Research Ethics Committee (Protocol: 2007/0094).

9.2.2.1. Inclusion criteria

Both stroke and non-stroke subjects were included if they were over 40 years of age and were able to walk 10 metres.

9.2.2.2. Exclusion criteria

Subjects who had a diagnosis of osteoporosis (defined as not on active treatment or diagnosed by DEXA scan with a T score <2.5), back problems associated with Crohns disease, Scheuermanns disease, previous spinal fracture or surgery, previous thoracotomy, severe heart disease exacerbated by exercise, pregnancy, diagnosis of neuropathy or myopathy, or other lower limb disability were excluded.

Stroke subjects were excluded if they scored of < 2 on the Rankin Scale (appendix D) immediately after they suffered a stroke.

9.2.2.3. Withdrawal of subjects from the trial

All subjects were informed in writing and verbally of their right to withdraw from the trial at any time. In addition, they were advised to contact the trial co-ordinator should they suffer pain or disability either as a direct result of the intervention or from any other cause. The decision to withdraw would then be made depending on the subject's wishes and/or the trial co-ordinator's judgment.

9.2.3. Interventions

The interventions were a progressive resisted back extension strengthening programme which was performed in a community based gym and a short course of postural re-education designed and supervised by experienced physiotherapists working in private practice. Further details are as follows.

9.2.3.1. The strengthening intervention

The strengthening intervention was conducted in one of two gyms located in the north and south of the city for geographical convenience. The back strengthening machines used are shown in Figure 9.2. Because both machines (Nautilus Nitro and Calgym back extension machines) were principally designed to strengthen the lumbar extensors, both machines were modified to target the thoracic extensors better by the addition of a simple foam pad which was attached to the part of the machine which made contact with the back. The pad was located between the scapulae at the level of approximately T4 when seated upright (Figure 9.2) and facilitated the subjects to retract their scapulae. This position was the same as that used to evaluate BES with the myometer in this study as described previously (chapters 5, 7 and 8). The pads were differently shaped to accommodate the different machines (Figure 9.2, c and d).

The instructions given to the subjects are shown in Figure 9.3 and were the same for both machines except for the fact that, due to the downward tilt of the seat on machine 2, the feet were positioned on the footplates which were positioned at maximum length to avoid pushing off through the legs.

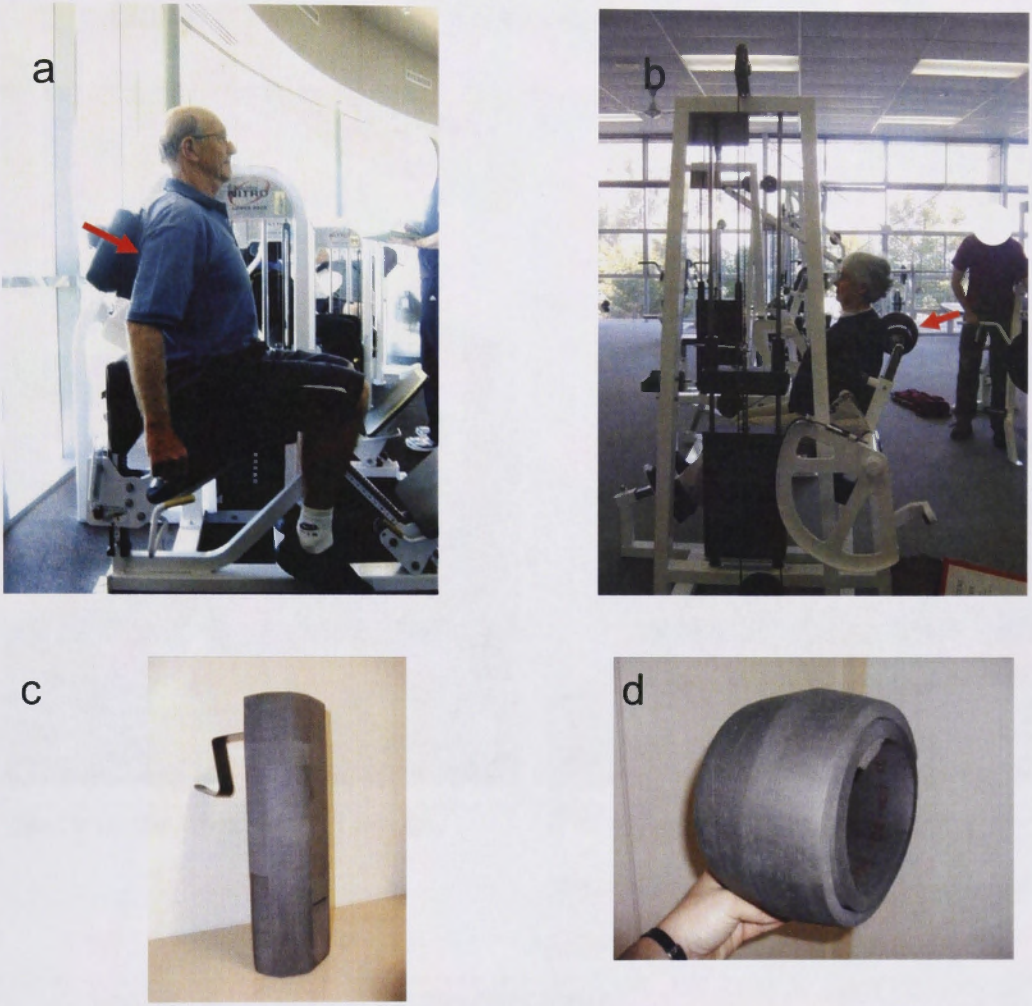
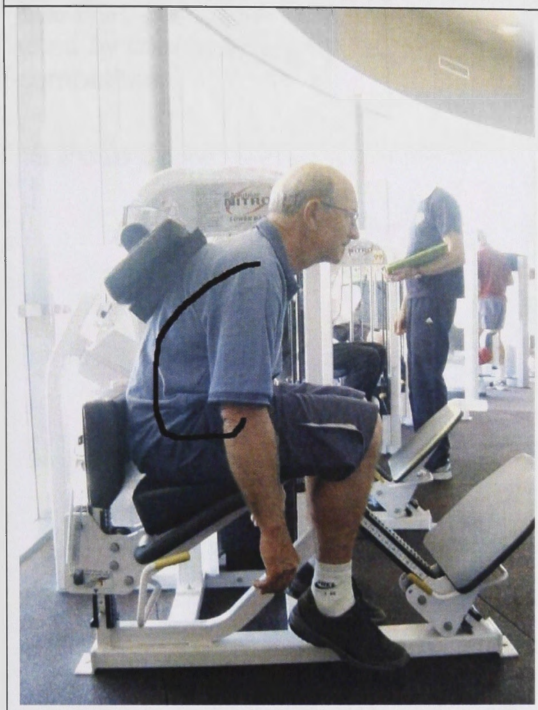
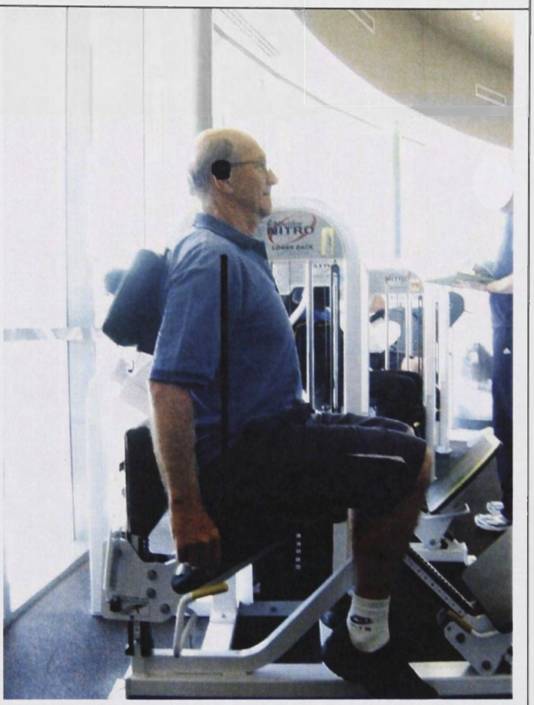


Figure 9.2. The two exercise machines located at two gyms used for the strengthening intervention (a & b) and the high density foam pads used to modify the back rests (c & d). Red arrows indicates the position of the pad on the machines.

Note. a. Nautilus Nitro (Nautilus inc, Vancouver, WA) with 2.27kg weight increments; b. Calgym back extension machine (Calgym, Calloundra, Qld, Australia) had 1.25kg increments

<table>
<tr><th colspan="2">Back Straightening Exercise for Posture Study</th></tr>
<tr><td></td><td></td></tr>
<tr><td>Start with the back shaped like a C</td><td>Push back and up until the back is shaped like a straight i with your head as the dot</td></tr>
</table>

- Position pad between the shoulder blades
- Select the assigned weight
- Arms by the side, do not push through your feet
- Push up and back until you are upright and straight with your chest opened out in front
- Hold for a count of four
- Slowly lower down into a C position as above
- Repeat
- Ideally you should breathe in on the way up, and out on the way down.

Figure 9.3. Instruction sheet for subjects randomised to the strengthening intervention

The Borg Scale

The Borg Scale is a simple method of rating perceived exertion (RPE) and can be used by coaches to gauge an athlete's level of intensity in training and competition.

15 Point Scale

6	20% effort	
7	30% effort	Very, very light (Rest)
8	40% effort	
9	50% effort	Very light - gentle walking
10	55% effort	
11	**60% effort**	**Fairly light**
12	65% effort	
13	70% effort	Somewhat hard - steady pace
14	75% effort	
15	80% effort	Hard
16	85% effort	
17	90% effort	Very hard
18	95% effort	
19	100% effort	Very, very hard
20		Exhaustion

Figure 9.4. The Borg rating of perceived exertion scale which was taught to the strengthening intervention subjects in order that they could increment their resistance to maintain effort at 60% throughout the 12 week intervention.

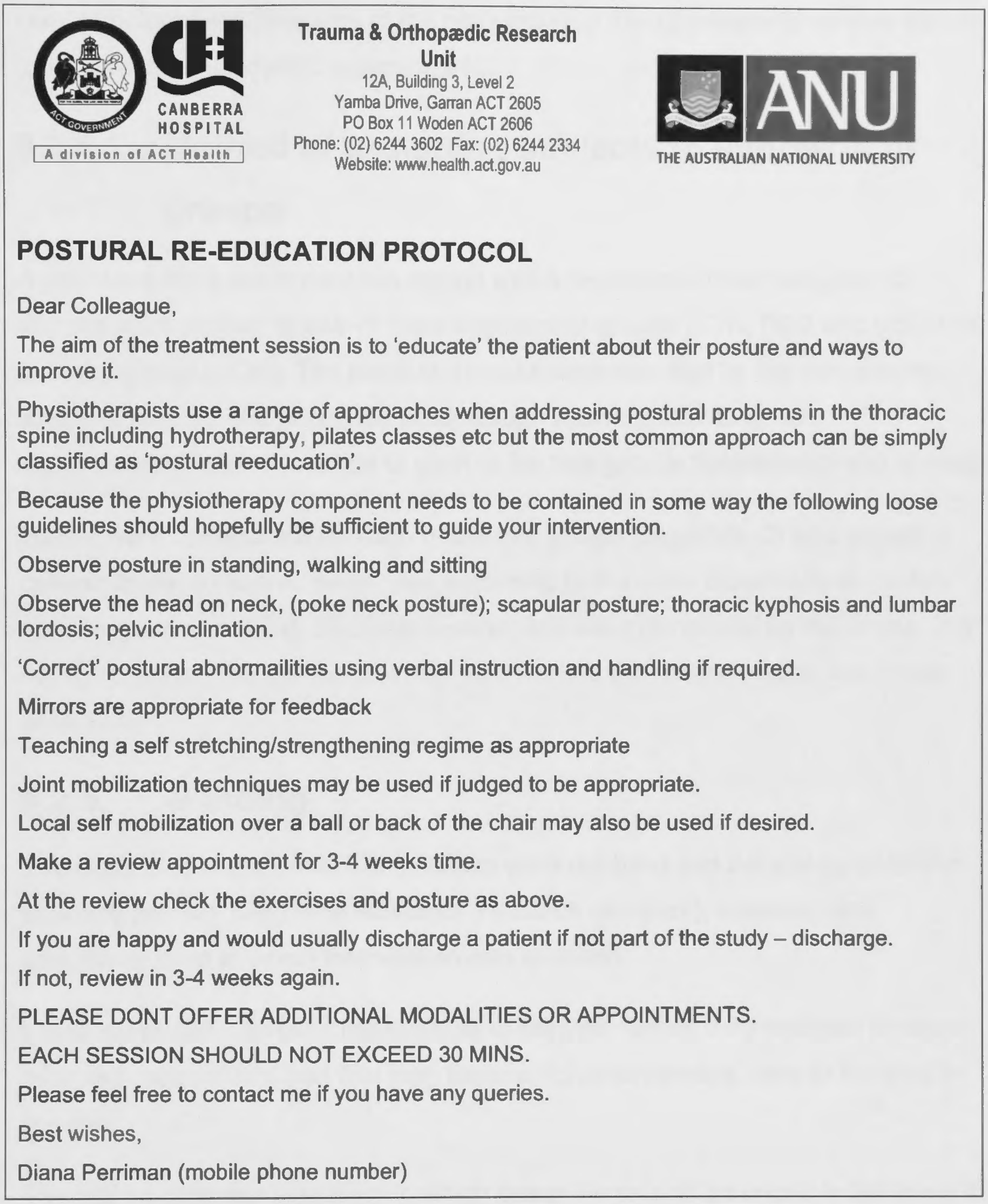
Adapted from Borg, G., *Perceived exertion as an indicator of somatic stress.* Scand J Rehabil Med, 1970. 2(2): p. 92-8.

The maximum weight which the subject could satisfactorily sustain during a controlled extension effort from full flexion to upright sitting (1RM) was determined in the first gym session with the trial co-ordinator.

The protocol required that the subject perform 4 x 10 repetitions of full range thoracic extension at 60% of 1RM three times a week because this dose has been reported to be optimal for strengthening untrained people [602] (2.9.2.2). So, 60% of this weight was loaded onto the machine and the resistance was compared with a rating of perceived exertion scale (Borg scale) [603] (Figure 9.4) in which 60% of 1RM is described as 'fairly light'. If the weight was too heavy or light according to the Borg scale it was modified until both the subject and the trial co-ordinator were happy with the weight being used. The subjects were instructed to use this weight to perform 4 X 10 repetitions of the resisted exercise two more times that week. Thereafter, the subjects were instructed to use of the Borg scale (Figure 9.4) as a way of judging how much to increment the weight in order to keep the resistance at 60% of 1RM. In this way the subjects were guided to increase the resistance gradually as they became stronger. The weights, session dates and number of completed sets were recorded by the subject and the record was used to assess compliance at the completion of the trial. The trial co-ordinator reviewed the subject twice more during the course of the 12 week intervention at, or around, 4 weeks and 8 weeks in order to check that the subject was performing the exercise safely and incrementing the weights appropriately. The subject was instructed to contact the trial co-ordinator if any problems, such as pain or discomfort, arose.

9.2.3.2. The postural re-education intervention

The postural re-education intervention was conducted by two established physiotherapy practices (primarily by two senior physiotherapists within the practices, each with 28 – 30 years of experience) and one experienced neurological physiotherapist with 26 years of clinical experience who assessed and treated the people in the stroke group. In collaboration with the practice owners, instructions were developed for the guidance of the treating physiotherapists (Figure 9.5). These instructions were deliberately loose in order to allow the physiotherapists to employ a variety of techniques that they might 'usually' employ when seeking to improve the posture of a client. The survey described in chapter 4 indicated that the mean number of sessions which Australian physiotherapists allocate to improving posture in people with thoracic hyperkyphosis is three. However, after consultation with the physiotherapists involved, the option to dispense with the third was made available. Therefore, no fewer than two sessions were given with three being the maximum.



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THE AUSTRALIAN NATIONAL UNIVERSITY

POSTURAL RE-EDUCATION PROTOCOL

Dear Colleague,

The aim of the treatment session is to 'educate' the patient about their posture and ways to improve it.

Physiotherapists use a range of approaches when addressing postural problems in the thoracic spine including hydrotherapy, pilates classes etc but the most common approach can be simply classified as 'postural reeducation'.

Because the physiotherapy component needs to be contained in some way the following loose guidelines should hopefully be sufficient to guide your intervention.

Observe posture in standing, walking and sitting

Observe the head on neck, (poke neck posture); scapular posture; thoracic kyphosis and lumbar lordosis; pelvic inclination.

'Correct' postural abnormailities using verbal instruction and handling if required.

Mirrors are appropriate for feedback

Teaching a self stretching/strengthening regime as appropriate

Joint mobilization techniques may be used if judged to be appropriate.

Local self mobilization over a ball or back of the chair may also be used if desired.

Make a review appointment for 3-4 weeks time.

At the review check the exercises and posture as above.

If you are happy and would usually discharge a patient if not part of the study – discharge.

If not, review in 3-4 weeks again.

PLEASE DONT OFFER ADDITIONAL MODALITIES OR APPOINTMENTS.

EACH SESSION SHOULD NOT EXCEED 30 MINS.

Please feel free to contact me if you have any queries.

Best wishes,

Diana Perriman (mobile phone number)

Figure 9.5. Instruction letter for the physiotherapists who executed the postural re-education protocol

All subjects were given a home programme of suitable exercises with the aim of improving their posture. Adherence with the home exercises was assessed in a semi-structured exit interview at the completion of the 12 week intervention period (questions are included in appendix F1).

9.2.4. Method of assigning subjects to intervention groups

A permuted block randomisation design with a block size of four was used to allocate each subject to one of three intervention groups (STR, PED and BOTH) or a control group (CON). The permuted blocks were stratified by the two cohorts - stroke or normal. The permuted block design was intended to ensure approximately equal allocation to each of the four groups (intervention and control).

Letters were constructed for each of the four groups (appendix C) and placed in consecutively numbered envelopes according to the order dictated by a random number generator [604]. Separate number lists were generated for the stroke and normal cohorts. The trial co-ordinator was blind to the randomisation and group allocation.

9.2.5. Blinding

The study was single blind. The subjects were not blind and the trial co-ordinator was only partially blind. The evaluator (research assistant), however, was completely blind to which intervention was received.

It was not possible to blind the subjects to the intervention they received because informed consent required that they knew which interventions were to be used in the trial.

The trial co-ordinator was blind to which group the subject belonged to but knew if they had received strengthening or not because she was responsible for teaching and monitoring that intervention.

The evaluator was one of two research assistants who were trained in how to conduct the measurements repeatably by the trial co-ordinator. The trial co-ordinator was required to assist with the assessments and to attach the FEG[*]. The evaluator timed the functional tests and read the measurements from the dynamometer and the FEG datalog for the clinical measures. The trial coordinator downloaded and processed the 6 hour FEG traces but did not influence the recording in any way.

9.2.6. Prior and concomitant therapy

The subjects were instructed that they should not change their current habits with respect to exercise and other therapies. For example, if they attended the gym prior to entering the study then they were advised to continue their current programme. Alternatively, if they did not do regular exercise they were requested not to commence any until after they completed the study.

9.2.7. Compliance

The subjects who attended the gym kept a record of their attendance. The subjects who received postural re-education reported on how many sessions they attended. Compliance with the home programme recommended by the physiotherapist was assessed in the semi-structured exit interview after completing the study.

9.2.8. The response variables

The response variables are summarised in Table 9.1. The thoracic angle measurements (FEG and inclinometer) were the primary response variables and the myometry measurements and the physical function tests, physical activity score and pain visual analogue scales were secondary response variables. The frequency measurements were exploratory given that these type of data has not previously been reported.

---

[*] The trial co-ordinator was a qualified physiotherapist who was skilled in spinal palpation, which was necessary for the repeatable placement of the FEG.

Table 9.1

The procedure for each of the response variables.

Response variable		**Summary of Procedure**
FEG angle	upright	Instructed to stand as tall as possible
	relaxed	Instructed to stand in usual position
	toes	Instructed to touch toes without bending knees
	ceiling	Instructed to look at the ceiling and reach up as far as possible
	deep breath	Instructed to take a deep breath and hold
	walking	Instructed to walk and turn within a small assessment room
	6hr mean	Mean of the recording taken over the course of a day doing usual activities
	6hr mode	Mode as above
	6hr min	Minimum angle recorded over the day (if greater than zero)
	6hr max	Maximum angle recorded over the day
	6hr range	Maximum minus the minimum angle recorded over the day
Inclinometer (T1-T12)	upright	Instructed to stand as tall as possible while inclinometer recorded angle measured between T1 spinous process and T12.
	relaxed	Instructed to stand in usual position and measured as for upright
Myometry	Torque	Seated myometry, best of three measurements
	Torque/weight	Force measured as above normalised by body weight
Physical function tests	10 metre walk test	Time to walk 10 metres along a straight flat carpeted walkway
	Timed up and go	Time to stand up from a chair, walk 3 metres, turn and return to sit in the chair
	X5 sit to stand	Time to stand from a chair and sit again 5 times
	Timed stairs	Time to climb 4 steps, turn and walk down again, 3 times

Table 9.1 continued

Response variable		Summary of Procedure
Chest Expansion		Measurement of chest circumference in full inspiration minus full expiration
Movement frequency	6hr-sag and 6hr-cor	Number of times the rotation angle changes by more than 5 degrees in an hour over the course of a day in the sagittal (sag) and coronal (cor) planes
	Walk-sag and walk-cor	As above when walking
	Drive-sag and drive-cor	As above when driving or as a passenger
Physical Activity Score		Amount of activity conducted in the previous week measured in METs
Pain Visual Analogue Scale (VAS)	Thoracic	Level of 'upper back' pain expressed as mark on a 100 mm line where 0 = 'no pain' and 100 = 'worst imaginable pain'
	Cervical	Level of neck pain on VAS as for thoracic
	Lumbar	Level of low back pain on VAS as for thoracic

Note. sag = sagittal plane, cor = coronal plane (Figure 2.14). *1 MET* = the energy (oxygen) used by the body in quiet sitting The Australian self reported physical activity score estimates the number of METs used by the subject during the week previous to completing the report (appendix B6).

9.2.8.1. The FEG measurements – kyphotic angle and movement frequency

The FEG is a validated tool for the dynamic measurement of the thoracic spine [584] and it has been described in both 2.6.4.7 and chapter 3. The method used to apply the FEG, as well as all of the measurement positions, are described in detail in chapter 3 (3.2.2). After the static measurements listed in Table 9.1 were made in the clinic, a 6 hour record of dynamic activity was captured using the FEG (6hr FEG). The datalog (Biometrics Ltd) unit was placed into a 'bum bag' which was positioned over the left or right anterior pelvis. This position was chosen because it enabled a car seatbelt to be fastened and least impeded movement. The subjects were instructed to undertake their usual activities of daily life, with the exception of bathing or swimming, with the FEG in place.

The subjects were asked to keep a chart of their activities during the 6 hours of recording in order that the trace could be interpreted if required. The chart was divided into 10 minute periods. After approximately 6 hours the unit was removed either at the clinic, at home, or at work. The data was downloaded onto Biometrics datalog PC software version 7.50. All angular data were collected at a rate of 1 Hz. The mean, maximum, minimum and range of the dynamic angular data recorded over the day (6hr) were calculated using the biometrics software. The mode was calculated using Stata version 10.1 (Statacorp, Texas USA).

The frequency of the change in FEG angle greater than 5° (movement frequency) was measured using the Biometrics software. Other thresholds were possible but 5° was selected as the threshold for this study because it is the angular change which is used clinically to represent a significant change of kyphotic angle from X-ray measurements [332]. The inter-segmental frequency measurements were made in both the sagittal and the coronal planes because the FEG is capable of measurement in both planes simultaneously. The measurements were made over 6 hours (as above) and data subsets were derived from this recording for walking and driving.

There are no data relating to clinically significant differences in movement frequency but finite element modelling experiments have predicted that a dynamic compression frequency of 0.1Hz would result in significant increases in oxygen concentration and decreased lactate concentration even in degenerated intervertebral discs [273] (see 2.5.1.3). This frequency would equate to 360 cycles per hour.

9.2.8.2. Inclinometer measurements

An electronic dual inclinometer (Dualer IQ, JTech Medical, Utah) (2.6.3.3) was used to measure the thoracic angle between T1 and T12 during upright and relaxed standing. The unit was zeroed against a flat, vertical surface (door) and the angle was read from the digital display. Although the electronic dual inclinometer has not been validated, it has been used to measure thoracic spinal angles in previous studies [366] and is the electronic equivalent of the inclinometer which has been validated for use in the thoracic spine [7].

9.2.8.3. Myometry

The details of the seated method of back extensor strength testing used in this study have been reported previously (chapters 7 and 8). Both the raw force measurement in Newtons and the force normalised by body weight (N/kg) as described by Katzman (2007) [8] were reported. A minimally significant difference for the raw force measurement of 20.7N was determined in the validation study (chapter 8). The force measurement was normalised because in sitting, heavier people may have been potentially advantaged by their weight.

9.2.8.4. 10 metre walk test

The 10 metre walk test is a valid and commonly used functional outcome measure for people with and without stroke [605-607]. Gait velocity has been reported to be the single most useful predictor of functional health status [608]. Although the use of both usual and fastest walking speeds have been reported [605, 609], fastest walking pace was used in this study because it was judged to be more reproducible. Normal values, for people between the ages of 40 and 80 years, of time taken to walk for 10 metres at a fast pace are between 5.9 and 7.1 seconds [610].

The subjects started their walk 1.5 metres behind the line from which they were timed and were instructed to continue walking past the finish line. In this way, the time measured did not include an acceleration and deceleration phase as is common practice when measuring gait velocity [610]. The walking surface was carpeted and the start and finish line were marked with tape. The time was recorded manually with a stop-watch which was accurate to 10 ms. The recorded times were rounded to the nearest 100 ms. All subjects had one practice walk before the walk was timed.

9.2.8.5. The timed up and go

The timed up and go test (TUAG) is a validated measure of mobility and balance in people with and without stroke [611, 612]. The time taken to rise from a chair (height 46.5 cm) without pushing through the arms, walk 3 metres, turn, and return to the chair to sit without using the chair arms was measured. All subjects had one practice before the TUAG was timed. The time commenced after a three digit countdown and finished when the subject's bottom touched the seat. Normal TUAG for community-dwelling women aged between 65 and 85 has been reported as 12 seconds or less [611, 613]. It has been used as a measure of balance and postural control [63].

9.2.8.6. The X5 sit to stand test

The X5 sit to stand test is a measure of balance, strength and postural control [614-617]. It has been validated for use in people with and without stroke [615, 616, 618]. The test involves standing up from a chair (height 46.5 cm) and sitting down five times as quickly as possible without pushing through the arms [615]. The timing commences from a three digit countdown and finishes when the subject's bottom touches the seat after the final stand. In this study the subjects were instructed not to lean back into the seat and to reach balanced upright standing before sitting again. A practice session of just one stand preceded the test since practicing all five stands would have tired many of the subjects too much to complete the test successfully. Times of greater than 11.4 seconds (60 to 69 years), 12.6 seconds. (70 to 79 years), and 14.8 second. (80 to 89 years) are repoted to be below average [619].

9.2.8.7. The stair test

The stair test involved ascending and descending 4 steps three times using the handrail for intermittent balance if required. This test is part of the motor assessment scale which was developed and is commonly used to assess physical ability in people with stroke [620]. The stair test constitutes the highest level of achievement in the walking sub-category. In the motor assessment scale the subjects are required to complete the task in less than 35 seconds to achieve the top level but, in this study the test was modified to a timed test to avoid the ceiling effect which is reported to occur with the 35 second criteria [621]. In this study the timing started after a three digit countdown and finished after both feet had touched the floor at the foot of the stairs at the end of the third descent. The subject was required to turn and descend the stairs facing forward. The stair test was used to test higher levels of balance and postural strength.

9.2.8.8. Chest expansion measurements

Chest expansion measurements were taken using a cloth tape measure using a method which has been previously validated [622]. While standing with the feet in the standardised position used for positioning the FEG, the tape measure was passed around the thorax at the level of the 10th thoracic spinous process and the xiphoid process. The T10 spinous process had been marked on the skin as part of the procedure for positioning the FEG. With the tape measure being held in place posteriorly, the subject was instructed to take their deepest breath and hold for a few seconds before breathing out maximally. This was repeated twice more while the maximum and minimum circumference was recorded. The tape measure was allowed to lengthen and was tightened again by the research assistant during each breath. The reseach assistant ensured that the tape was firm enough not to slip out of place but not tight. The difference between the maximum and the minimum measurement (mm) was recorded as the chest expansion.

9.2.8.9. The physical activity score

The Australian Self-Reported Generic Physical Activity Questionnaire (appendix B6) is a validated tool which collects information on walking continuously for at least 10 minutes for recreation, exercise or transport; other moderate-intensity leisure-time physical activity; and vigorous-intensity leisure-time physical activity [623]. The tool estimates the number of metabolic equivalents (amount of oxygen used by the body during physical activity) expended over the previous week. The questionnaire was sent to all the subjects prior to the initial (baseline) and 12 week assessments. The tool was used in order to evaluate the effect of the study interventions on overall day-to-day physical activity.

9.2.8.10. The visual analogue scores for pain

Visual analogue scales (VAS) have been validated [624] and are commonly used to evaluate pain in a variety of settings [625]. In this study a 100 mm horizontal scale was used. 'No pain' was marked on the far left of the line and 'worst possible pain' was marked on the far right. The subjects were asked to use this scale to indicate the level of pain that they commonly suffered in their neck, upper back (thoracic spine) and lower back (lumbar spine). The scale was measured in cm and was used to measure changes in pain associated with the study interventions. The minimum clinical significant difference in VAS (i.e. the mean difference between current and preceding score when the patient reported that the pain was "a little better" or "a little worse") has been reported to be 11 mm for "mild pain, 14 mm for "moderate pain" and 10 mm for "severe pain" [626].

9.2.8.11. Postural type categorization

All subjects were categorized into four postural types according to the guidelines established by Kendall [445]. These were 'Normal", Kyphosis/Lordosis (K/L), Sway-back and Flat-back. These postural classifications are in common clinical use [446]. In this study the subjects were photographed in relaxed standing from a distance of 205 cm with the camera (Sony Cyber-shot Model No DSC S950; Sony Corporation, Tokyo, Japan) held at 144 cm from the floor. The subjects wore flat walking shoes and removed their upper clothing only, so that their torso was exposed but not their lower limbs. The classification was done by the trial coordinator who is an experienced physiotherapist but skin markers were not used to identify anatomical landmarks as was the case in a previous study [446]. Instead, the trial co-ordinator used Kendalls's guidelines as would be the case in clinical practice. The subject of postural classification has been discussed in chapter 2 (2.8).

9.2.8.12. The functional co-morbidity index

The functional co-morbidity index (FCI) is a simple self-administered questionnaire [627] (see appendix B5). It was used to describe the cohort more accurately. It differs from other co-morbidity indices because it is designed to have physical function as the outcome rather than mortality [627] and has been validated as a measure of physical health status [628]. The scoring system simply requires the subjects to indicate whether or not they have had any of the 17 diagnoses listed and to supply their height and weight so that body mass index (BMI) can be calculated (BMI > 30 incurred a score of 1). The maximum score for the FCI is 18. The questionnaire was sent to all the subjects prior to the initial (baseline) assessment.

9.2.9. Statistical analyses

The data analysis was performed using Stata version 10.1 (Statacorp, Texas USA).

The data were expressed as the mean and standard error of the mean (SE) unless otherwise stated. The minimum and maximum values were included in some tables to describe data variability.

A summary of the baseline data were included for reference only. The data were expressed by cohort (normal and stroke) but no statistical comparisons were made between the groups at baseline.

Linear regression models, adjusted for baseline value, cohort (normal and stroke), age, gender, strengthening (Y/N), postural re-education (Y/N) and strengthening by postural re-education interaction were used to evaluate the changes between the baseline and 12 week data in each of the response variables. The data were reported as marginal means* and associated standard errors based on values calculated using the mean baseline values in the study population.

Linear regressions were also used to assess the effect of age, gender, BMI and cohort (normal or stroke). The model controlled for baseline values, age, BMI, gender, cohort and intervention (control, strengthening, postural re-education and both). The data were reported as marginal means and associated standard errors

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* The marginal mean is the mean response for a factor averaged across all levels of another factor or factors

based on values calculated using the mean baseline values in the study population.

Response variables were assessed for normality by visual interpretation of histograms.

The degree of correlation was assessed using Pearson's correlations with pairwise deletion of missing values and t-tests for significance.

Principal component analysis was used to explore the relationships between the baseline variables and the relationships between the differences between the baseline measurements and the 12 week measurements. The factors which emerged were reported using loading plots and, where correlations existed, were verified by comparing the results with correlation matrices of the same variables (Pearson's correlation).

Differences were considered significant when $p < 0.05$ but in the case of some variables minimal significant differences were also considered.

9.3. Results

9.3.1. Subject Recruitment

Consort diagrams for the normal and stroke cohorts are shown in Figures 9.6 and 9.7. The reasons for exclusion are shown in Table 9.2. The primary reason for exclusion in the normal group was a diagnosis of osteoporosis. In the stroke group the most frequent reason for exclusion was the mildness of the disability resulting from the stroke. The severity of their stroke was determined using a modified Rankin scale in which structured questions enabled the interviewer to determine a score out of 5 where '0' = 'no symptoms or limitations' and '5' = 'severe disability' (appendix D). Subjects with a score of <2 immediately after they suffered a stroke were excluded. In the normal cohort, 61 subjects were randomised and 56 completed the study. In the stroke cohort 14 subjects were randomised and 13 completed the study. Recruitment to the stroke cohort was limited because the participants needed to be able to walk 10 metres and potentially attend a gym 3 times a week.

Table 9.2

Reasons for exclusion for the normal and stroke cohorts

Normal cohort		Stroke cohort	
Reason	N	Reason	N
Osteoporosis	4	Initial modified Rankin scale < 2	9
Previous severe spinal problems	2	Cerebellar stroke	1
Scheuerman's Disease	1	Previous spinal Injury	1
Muscular dystrophy	1		
Peripheral Neuropathy	1		
Thoracotomy	1		
Lower Limb Amputee	1		

Note. The modified Rankin scale is a method of grading the functional severity of a stroke by structured interview.

Figure 9.6 Consort diagram for the normal cohort

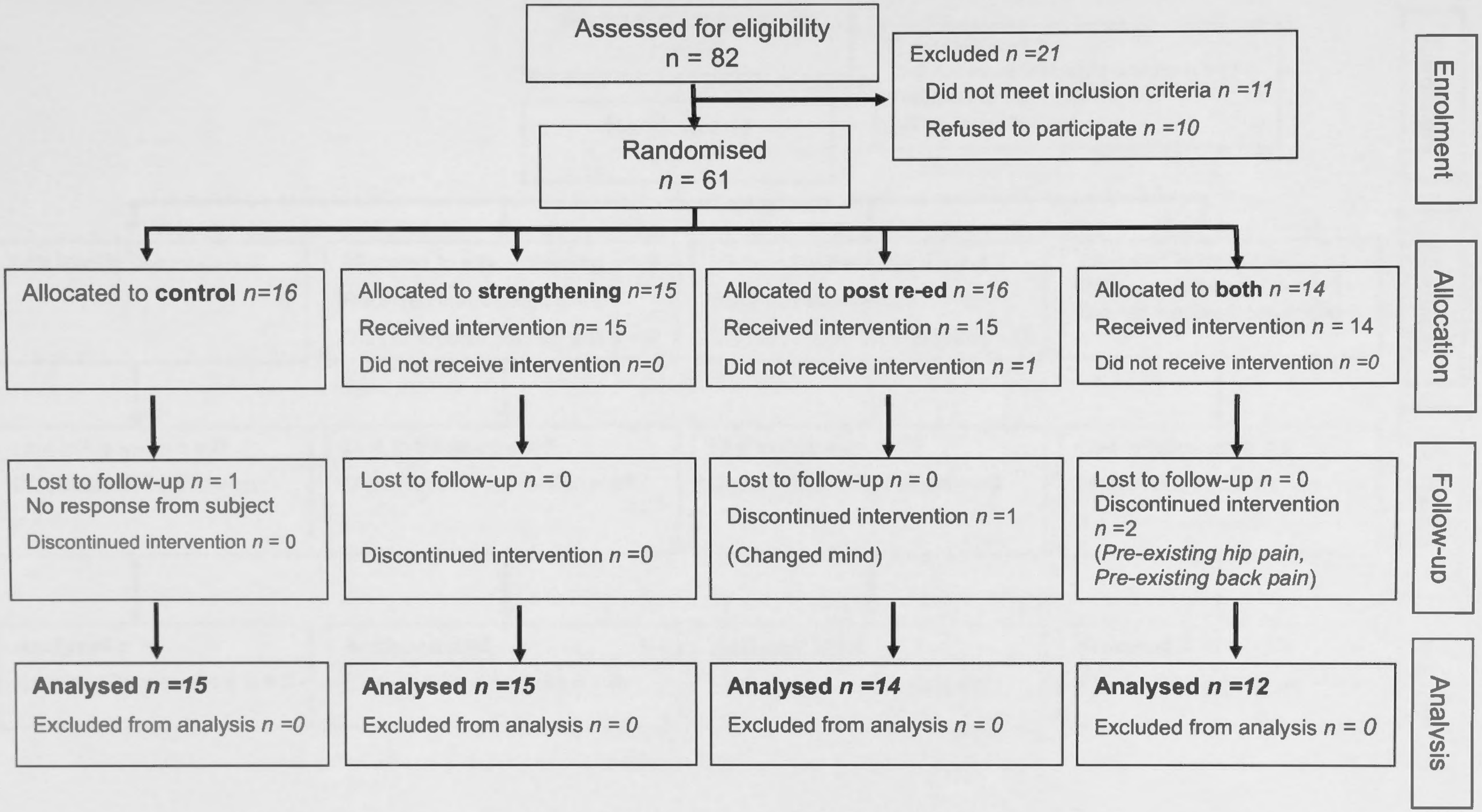
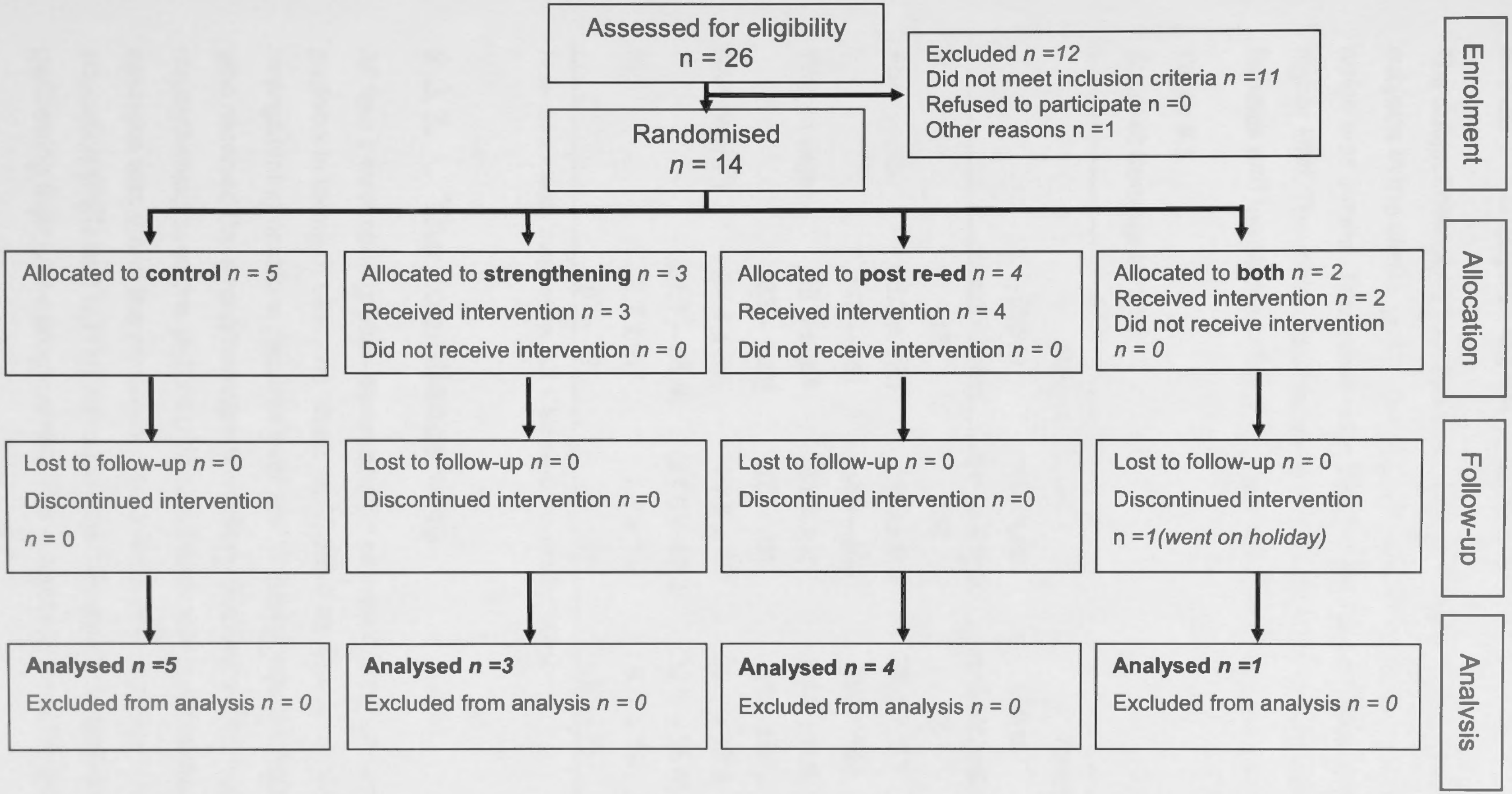


Figure 9.7 Consort diagram for the stroke cohort



9.3.2. Subject demographics

The subject demographics are described in Table 9.3. The mean age of the female subjects in the stroke group was slightly older than the normal subjects but the age range was similar. The males were heavier than the females and had a slightly higher BMI. The males had higher functional co-morbidity index values than the females and the stroke cohort had higher values than the normal group.

Table 9.3

Subject demographics

	Normal Group		Stroke Group	
	Males	Females	Males	Females
	Mean ± SD (range)	Mean ± SD (range)	Mean ± SD (range)	Mean ± SD (range)
N	18	38	8	5
Age (years)	65.3 ± 13.7	61.0 ± 9.5	66.5 ± 4.7	69.2 ± 17.5
	(40 – 85)	(40 – 83)	(54 – 76)	(40 – 82)
Weight (kgs)	85.0 ± 9.4	65.9 ± 8.7	88.3 ± 8.8	65.8 ± 15.6
	(63 – 100)	(51 – 90)	(69 – 105)	(51 – 90)
BMI (kg/m^2)	27.1 ± 3.8	24.7 ± 2.7	28.9 ± 12.3	25.3 ± 4.1
	(21.1 – 35.9)	(21.0 – 35.0)	(22.0 – 38.0)	(22.0 – 32.0)
FCI	2.7 ± 2.7	1.2 ± 1.2	4.0 ± 2.6	3.2 ± 1.9
	(0 – 10)	(0 – 4)	(0 – 7)	(1 – 6)

Note. BMI = body mass index FCI = functional co-morbidity index

9.3.3. The compliance data

All four intervention groups demonstrated excellent compliance with the study protocol in terms of sessions attended (Table 9.4). The maximum number of strengthening sessions required over the 12 weeks was 36. Both of the groups who received the strengthening intervention attended a mean of over 30 strengthening sessions (> 83%). The minimum number of postural re-education sessions was 2 and the maximum was 3. Both of the groups who had postural re-education (PED and BOTH) attended approximately 2.5 sessions (as well as performing their home programme). The subjects in the STR group attended more strengthening sessions than the BOTH group (89% vs 85%). The number of postural re-education sessions attended by the PED and the BOTH groups were almost identical (Table 9.4). One subject in the BOTH group attended just one postural re-education session.

Table 9.4

Compliance with the protocol in terms of number of strengthening and or postural re-education sessions attended by intervention group

	CON	STR	PED	BOTH	Total
Strengthening sessions	0	32.2 ± 4.3 (23 – 36)	0	30.5 ± 4.4 (24 – 36)	31.5 ± 4.4 (23 – 36)
Postural re-education sessions	0	0	2.6 ± 0.5 (2 – 3)	2.5 ± 0.7 (1 – 3)	2.6 ± 0.6 (1 – 3)

Note: Data expressed as mean ± SD (range). Maximum gym sessions = 36. Maximum physiotherapy sessions = 3. CON = control, STR = strengthening only, PED = Postural re-education only and BOTH = both strengthening and postural re-education.

9.3.4. The baseline data

Descriptions of the baseline data for all of the response variables in terms of mean, standard error and range are shown in Table 9.6 to Table 9.9. These data are divided by cohort for easy comparison of the data between the normal and stroke groups.

9.3.4.1. The thoracic angles

The section of the spine measured by the FEG varied according to individual anatomical differences* but the most common sections were between T3 and T10 or T11 (Table 9.5).

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* The unextended length of the FEG used in this study was 24 cm long (SG150). Therefore, the number of spinal segments covered by the FEG depended on the length of the individual spine.

Table 9.5

Section of the spine measured by the FEG by number of subjects (both normal and stroke cohort).

Spinal section	T2-10	T2-11	T3-9	T3-10	T3-11	T3-12	T4-10	T4-11
N	2	2	2	31	29	1	1	1
% of total	2.9	2.9	2.9	44.9	42.2	1.4	1.4	1.4

Note. Total N = 69. Shading is used to divide section groups starting at T2, T3 and T4.

The stroke subjects demonstrated slightly greater mean kyphosis angles for all the measurements (Table 9.6). The differences, however, were generally in the order of 2° which was smaller than the standard errors for most of the stroke cohort measurements. The largest angle difference between the cohorts was for the upright standing FEG angle which was 4° greater for the stroke cohort. However, the inclinometer angle (T1 to T12) for upright standing differed by only 2°.

Table 9.6

Summary statistics for baseline kyphosis angle variables (FEG and Inclinometer).

Response Variable	Normal				Stroke			
	mean	SE	min	max	mean	SE	min	max
Upright stand	22.9	1.2	6.0	43.0	26.9	2.9	12.0	55.0
Relaxed stand	30.8	1.1	16.0	48.0	32.1	2.7	18.0	59.0
Ceiling reach	20.0	1.3	4.0	43.0	22.0	3.3	7.0	56.0
Toes touch	35.6	1.2	-3.0	51.0	36.7	2.4	27.0	61.0
Deep breath	24.6	1.3	7.0	51.0	26.7	3.1	14.0	60.0
Walking	28.8	1.1	14.0	50.0	30.9	2.7	19.0	58.0
Inclin. upright	33.7	1.4	3.0	61.0	35.6	3.4	16.0	59.0
Inclin. relaxed	42.8	1.4	10.0	65.0	43.3	3.8	21.0	65.0
6hr mean	30.9	1.0	16.0	50.0	31.4	2.5	21.0	57.0
6hr mode	31.3	1.1	15.0	50.0	33.0	2.4	21.0	57.0
6hr max	42.7	1.1	30.0	68.0	44.5	2.4	31.0	66.0
6hr min	15.5	1.2	-1.0	37.0	16.1	3.5	4.0	49.0
6hr range	27.1	0.8	16.0	41.0	28.4	2.0	17.0	42.0

Note. The data expressed in degees. Inclin. = inclinometer which measured the thoracic angle between T1 and T12. All measurements were made using the FEG except for the two inclinometer measurements. The 6hr measurements were dynamic while the rest were static.

9.3.4.2. The physical ability measurements

The stroke cohort were slower to complete the timed activities, including the 10 m walk test, the timed up and go, the stair test, and the X5 sit to stand test (Table 9.7). The stroke cohort also recorded smaller myometry forces than the normal cohort and had slightly lower physical activity scores (Table 9.7). Only 12 of the stroke cohort could perform the timed up and go test and only 9 could perform the stair test at baseline. Subject 5 was much slower than the other subjects for both the 10m walk test and the timed up and go but did not attempt the stair test.

Table 9.7

Summary statistics for baseline physical ability variables

Response Variable	Normal cohort				Stroke cohort			
	mean	SE	min	max	mean	SE	min	max
10m walk test (seconds)	5.04	0.10	3.37	7.73	12.99	3.71	5.15	51.79
Timed up and go (seconds)	5.88	0.16	4.06	11.36	12.27	2.68	7.30	38.81
Stair test (seconds)	15.64	0.42	10.06	22.88	28.47	1.85	21.56	38.19
X 5 sit to stand (seconds)	11.63	0.39	7.00	19.90	18.99	2.20	10.09	39.28
Chest Expansion (mm)	53.5	2.5	20.0	105.0	42.1	6.3	10.0	105.0
BES (N)	222.56	8.25	103.20	453.40	184.11	19.12	82.20	288.80
Normalised BES(N/kg)	3.16	0.12	1.15	5.46	2.32	0.20	0.91	3.56
Phys activity score (METs)	1031.5	105.6	0.0	3360.0	823.5	233.5	0.0	3000.0

Note. BES = back extensor strength. The BES was also normalised by weight (Normalised BES). The unit for Physical Activity Score is metabolic equivalent (MET). *1 MET* = the energy (oxygen) used by the body in quiet sitting The Australian self reported physical activity score estimates the number of METs used by the subject during the week previous to completing the report (appendix B6).

9.3.4.3. The movement frequency of the thoracic spine

The movement frequency for the thoracic spine was very low, especially in the sagittal plane. The mean and associated standard errors, minimum and maximum data are presented in Table 9.8. The mean frequencies over the 6 hour period in the sagittal plane were only 5.21 and 4.26 cycles per hour for the normal and stroke cohorts respectively. The coronal plane movement frequency was approximately twice that of the sagittal plane movement frequency for both cohorts. The movement frequency for walking was greater at 6.13 and 5.76 cycles per hour in the sagittal plane (normal and stroke cohorts respectively). During walking the coronal plane movement frequency was 2.5 times greater than that of the sagittal plane movement frequency in the normal cohort and 2.2 times greater in the stroke cohort. The frequency during driving was low in both cohorts with sagittal plane frequency being just 2.98 and 3.92 cycles per hour and the coronal plane movement frequency being approximately twice that of the sagittal frequency. An exceptionally high maximum coronal plane frequency (55.44 cycles per hour) occurred in one of the stroke subjects (S14). Otherwise both the sagittal and the coronal movement frequency during walking were lower in the stroke cohort than the normal cohort.

Table 9.8

Summary statistics for baseline movement frequency variables in the sagittal and coronal planes for normal and stroke cohorts

Response Variable	Normal				Stroke			
	mean	SE	min	max	mean	SE	min	max
6hr-sagittal	5.21	0.32	1.80	11.88	4.26	0.69	0.72	9.36
6hr-coronal	10.44	0.62	2.88	21.60	8.17	1.21	1.08	18.00
Walk-sagittal	6.13	0.58	0.00	20.88	5.76	1.22	0.00	15.48
Walk-coronal	15.35	1.13	0.00	38.88	12.69	4.02	3.60	55.44
Drive-sagittal	2.98	0.41	0.00	11.88	3.92	1.42	0.00	14.76
Drive- coronal	5.58	0.71	0.00	21.24	5.11	1.30	1.44	11.88

Note. The frequency is expressed as cycles per hour in order to make the data more meaningful. Each cycle represents an angular movement > 5° (9.2.8.1). SE = standard error of the mean.

Testing for associations between movement frequency and age revealed that there was a weak but significant negative correlation between age and the 6hr sagittal (-0.24, $p = 0.04$) and coronal (-0.29, $p = 0.02$) movement frequency. However, during walking, the negative correlation was stronger for coronal plane movement frequency (-0.31, $p = 0.01$) while it was not significant for sagittal plane movement frequency (-0.17, $p = 0.18$).

9.3.4.4. The pain measurements

All of the mean pain measurements were low (Table 9.9) but the ranges were large with one subject reporting 91.3 (max = 100) for neck pain. The mean measurements for thoracic pain were lower than those for neck and lumbar pain in both the normal and the stroke cohorts.

Table 9.9

Summary statistics for baseline Pain Visual Analogue Scores

Response Variable	Normal				Stroke			
	mean	SE	min	max	mean	SE	min	max
Thoracic spine	7.3	2.6	0.0	80.3	1.0	1.0	0.0	13.2
Lumbar spine	9.0	2.2	0.0	69.3	17.5	7.1	0.0	81.4
Neck	11.4	2.9	0.0	91.3	12.4	7.1	0.0	74.8

Note. Visual Analogue scales were measured on a 100 mm horizontal line. All measurements are scored out of a maximum of 100 where 0 = no pain and 100 = the worst possible pain.

9.3.4.5. The distribution of the posture types

There were four posture types identified in the combined stroke and normal cohorts: Normal, Kyphosis/Lordosis, Sway-back, and Flat-back. Figure 9.8 summarizes the distribution of the posture types by gender.

The most common posture type was kyphosis/lordosis (56% of the females and 42% of the males). The second most prevalent posture type was sway-back (33% in females and 35% in males). Only 5% of the females had flat-back posture compared to 15% of the males. 'Normal' posture was relatively uncommon in both females and males (7% and 8% respectively).

Overall, the subjects classified as having kyphosis/lordosis posture type had the highest 6hr mean and mode angles but the angles recorded in the subjects classified as having sway-back posture type were similarly high (Table 9.10).

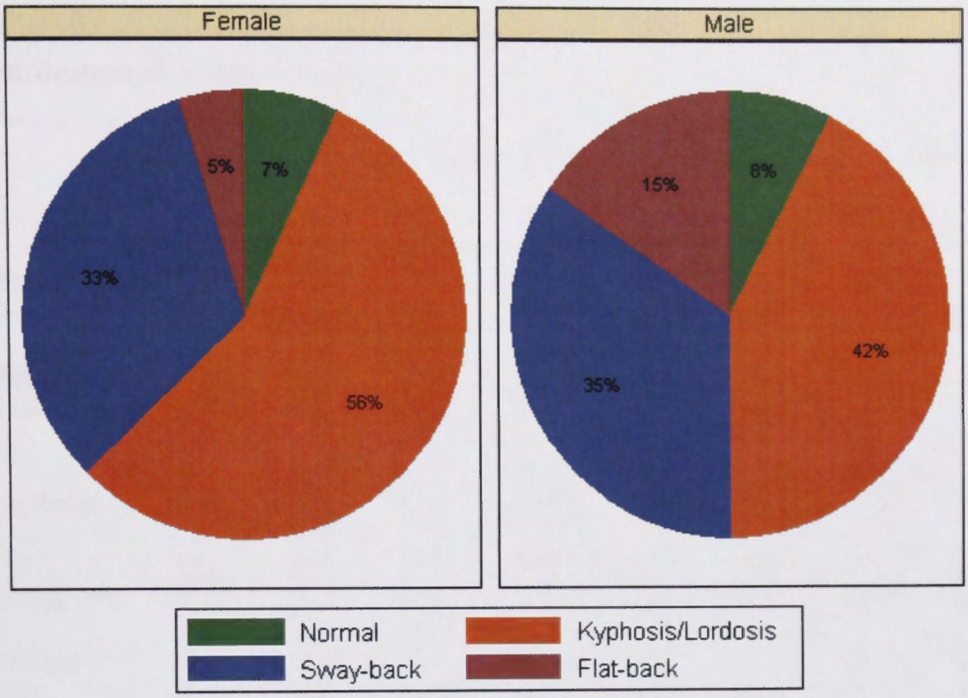

Figure 9.8 The distribution of posture types by gender.

Note. Combined normal and stroke cohorts.

9.3.5. Normality of the response variables

The data recorded for some variables were not normally distributed. The variables included 10m walk time, timed up and go, X 5 sit to stand, walking movement frequency, driving movement frequency, physical activity score and all three of the pain measures (thoracic lumbar and neck). The skewing of the data was principally due to two of the stroke subjects whose results were unusual. As a result these outlying subjects were not included in the principal component analysis (9.3.8.3).

Table 9.10

Summary of selected baseline FEG angles by posture type and the distribution of posture types

	Normal		Kyphosis/Lordosis		Sway-back		Flat-back	
	F	M	F	M	F	M	F	M
Mean 6hr FEG	25.3 (0.7)	30.5 (2.5)	33.7 (1.6)	29.1 (2.1)	33.1 (2.4)	26.7 (4.1)	26.0 (1.0)	28.0 (3.4)
Mode 6hr FEG	27.3 (1.5)	29.5 (5.5)	34.3 (1.7)	29.5 (2.3)	33.2 (2.4)	27.7 (4.3)	23.5 (3.5)	29.0 (4.2)
6hr Range	28.7 (1.9)	33.5 (3.5)	27.9 (1.4)	28.1 (1.9)	25.5 (1.4)	23.3 (2.2)	30.5 (3.5)	25.8 (2.2)
Upright FEG	12.7 (2.3)	24.5 (6.5)	24.3 (2.0)	23.1 (2.7)	27.1 (2.2)	23.0 (3.4)	15.5 (3.5)	21.0 (7.9)
Relaxed FEG	23.7 (2.0)	33.0 (3.0)	32.4 (1.9)	29.1 (2.5)	34.2 (2.0)	28.3 (4.6)	25.0 (6.0)	27.3 (4.9)

Note. Data expressed and mean (standard error of the mean). The data from both the normal and stroke cohort are included in this table.

9.3.6. The effects of progressive resisted strengthening versus postural re-education

The relative effects of the 12 week intervention for the combined normal and stroke cohorts are shown in Table 9.11, Table 9.12 and Table 9.13. The values shown in these tables are the marginal means of the differences between the baseline and 12 week measurements (see 9.2.9).

9.3.6.1. The primary outcome measures

There was just one significant difference between the marginal means for the CON group and an intervention group in this group of outcome measures. The BOTH group had a significantly smaller FEG angle when touching toes from standing ($p = 0.04$) Table 9.11. However, Table 9.11 also indicates the relative performance of the groups regardless of whether they reached significance or not. The shaded boxes indicate which group performed best for each of the individual outcome measures. The BOTH group performed best over the most measures. These included both static and dynamic (6hr) measurements.

9.3.6.2. The secondary outcome measures

The results for the secondary outcome measures are shown in Table 9.12. These measures can be subdivided into physical function measures, strength measures and pain measures.

The STR group performed best in the physical function measures with the times for the 10 metre walk and the x5 sit to stand being significantly reduced compared to the CON group (p = 0.031 and p = 0.024 respectively).

The STR group also demonstrated the most improvement in strength measurements with BES (normalised by weight) being significantly greater than the CON group (p = 0.007). The change in non-normalised BES was also greatest in the STR group (32.0 ± 16.1N) but it was not significantly different to the CON group (p = 0.07). However, it was larger than the minimum clinical significant difference (MCSD) of 21N reported in chapter 8 (8.3).

The only change in the pain score (VAS) which was significantly different to the CON group was for thoracic pain in the STR group in which decrease in VAS was lower (p = 0.048) Table 9.12. Both the STR and PED groups demonstrated a non-significant increase in VAS for lumbar pain. None of the differences in VAS were greater than the reported minimum clinical significant difference (MCSD) of 10/100 [626].

9.3.6.3. The exploratory outcome measures

There were no significant differences between the intervention groups and the CON group for changes in thoracic spine movement frequency Table 9.13). The negative values indicate that the movement frequency reduced over the 12 week intervention period.

The 6hr sagittal frequency increased in all of the intervention groups, most markedly in the STR group. The coronal frequency reduced in the STR and BOTH groups but increased in the CON and PED groups.

The frequency data for walking showed a marked decrease in coronal frequency accompanied by a smaller decrease in sagittal frequency in the STR group but these changes were not repeated in the BOTH group. The coronal frequency for the STR group decreased by 3.5 cycles per hour, which was the most marked change in the frequency data however the difference did not reach significance ($p = 0.086$).

The movement frequency measurements during driving were very low and there were no significant differences between the groups.

Table 9.11

The primary outcome measures for the four intervention groups (difference between baseline and 12 week angle).

Outcome Measure	CON	STR	PED	BOTH
FEG relaxed standing (degrees)	-0.3 (0.9)	-0.4 (0.9)	-1.4 (0.9)	-2.0 (1.1)
FEG upright standing (degrees)	-1.7 (1.1)	-1.5 (1.0)	-1.1 (1.0)	-1.8 (1.2)
FEG reach to ceiling (degrees)	-1.6 (1.0)	-0.8 (1.0)	-0.8 (1.0)	-3.2 (1.2)
FEG touch toes (degrees)	1.1 (1.2)	1.0 (1.3)	1.7 (1.3)	-3.1 (1.5)*
FEG deep breath (degrees)	- 0.5 (0.9)	- 2.5 (0.9)	- 0.9 (1.1)	- 2.6 (1.2)
FEG walking (degrees)	- 0.3 (0.7)	- 0.7 (0.8)	- 1.1 (08)	0.3 (0.9)
Inclinometer (T1-T12) upright (degrees)	- 2.1 (1.5)	- 4.1 (1.7)	0.8 (1.7)	- 3.4 (1.9)
Inclinometer (T1-T12) relaxed (degrees)	- 0.9 (1.5)	- 3.6 (1.6)	0.1 (1.7)	- 3.1 (2.0)
FEG 6hr mean (degrees)	- 1.1 (0.8)	- 1.0 (0.8)	0.4 (0.8)	- 2.0 (0.9)
FEG 6hr mode (degrees)	- 1.7 (1.0)	- 1.0 (1.0)	0.1 (1.0)	- 2.2 (1.2)
FEG 6hr min (degrees)	- 2.0 (1.3)	- 1.3 (1.3)	- 0.2 (1.4)	- 2.9 (1.6)
FEG 6hr max (degrees)	- 0.5 (1.0)	- 1.6 (1.0)	- 0.9 (1.0)	- 2.3 (1.2)
FEG 6hr range (degrees)	2.0 (1.2)	- 0.3 (1.2)	- 1.1 (1.3)	0.5 (1.5)

Note: CON = control, STR = strengthening only, PED = postural re-education only, BOTH = strengthening and postural re-education. Marginal means and associated standard errors are reported based upon a linear model, adjusting for baseline value, cohort (normal and stroke), age, gender, strength(Y/N), PostEd (Y/N) and Strength by PostEd interaction. Marginal means are calculated using the mean baseline values in the study population. The shaded boxes are those that produced the most favourable outcome compared to the control, but not all are significantly different to the control. FEG = flexible electrogoniometer. N=69 (combined normal and stroke cohorts)
*$p < 0.05$ significantly different from control

Table 9.12

The secondary outcome measures for the four intervention groups (difference between baseline and 12 week angle).

Outcome Measure	CON	STR	PED	BOTH
10 metre walk (s)	1.2 (0.6)	- 0.3 (0.6)*	0.3 (0.6)	1.0 (0.7)
Timed up & go (s)	0.9 (0.6)	0.2 (0.6)	- 0.3 (0.6)	0.2 (0.7)
Stair time (s)	- 0.2 (0.7)	- 0.4 (0.8)	- 0.5 (0.7)	- 2.3 (0.8)
Chest Expansion (mm)	- 5 (2)	1 (3)	- 2 (3)	1 (3)
X5 sit to stand (s)	0.9 (0.6)	- 0.9 (0.6)*	- 0.7 (0.6)	- 0.1 (0.7)
Physical Activity Score	295.1 (214.3)	121.1 (222.5)	- 72.7 (220.1)	- 24.4 (270.1)
BES (N)	- 9.8 (15.1)	32.0 (16.1)	0.0 (16.0)	10.5 (19.1)
BES (N/kg)	- 0.1 (0.2)	0.6 (0.2)**	0.1 (0.2)	0.1 (0.2)
Thoracic pain VAS (mm)	- 5.7 (1.0)	- 2.2 (1.0)*	- 2.7 (1.0)	- 5.7 (2.0)
Lumbar pain VAS (mm)	-0.5 (3.4)	6.4 (3.5)	0.5 (3.5)	-1.4 (4.1)
Neck pain VAS (mm)	-6.7 (3.1)	-4.7 (3.2)	-1.3 (3.2)	-1.8 (3.7)

Note: CON = control, STR = strengthening only, PED = postural re-education only, BOTH = strengthening and postural re-education. Marginal means and associated standard errors are reported based upon a linear model, adjusting for baseline value, cohort (normal and stroke), age, gender, strength(Y/N), PostEd (Y/N), and Strength by PostEd interaction. Marginal means are calculated using the mean baseline values in the study population. The shaded boxes are those that produced the most favourable outcome compared to the control, but not all are significantly different to the control. N=69 (combined normal and stroke cohorts)

*p < 0.05 significantly different from control

**p < 0.01 significantly different from control

BES = back extensor strength measured in sitting.

VAS = visual analogue scale (100mm)

Table 9.13

The exploratory outcome measures (movement frequency) for the four intervention groups (difference between baseline and 12 week angle).

Outcome Measure	CON	STR	PED	BOTH
6hr-sag (cycles per hr)	-0.1 (0.4)	0.4 (0.5)	0.1 (0.4)	0.1 (0.5)
6hr-cor (cycles per hr)	0.7 (0.9)	-0.6 (1.0)	0.2 (1.0)	-0.2 (1.1)
Walk-sag (cycles per hr)	0.7 (0.9)	-0.4 (0.9)	-0.3 (0.9)	-1.0 (1.1)
Walk-cor (cycles per hr)	0.8 (1.8)	-3.5 (1.8)	-0.3 (1.8)	2.8 (2.2)
Drive-sag (cycles per hr)	0.3 (0.7)	0.6 (0.8)	0.6 (0.7)	-0.3 (0.8)
Drive- cor (cycles per hr)	1.7 (1.3)	2.4 (1.4)	0.3 (1.3)	0.0 (1.5)

Note: CON = control, STR = strengthening only, PED = postural re-education only, BOTH = strengthening and postural re-education. Marginal means and associated standard errors are reported based upon a linear model, adjusting for baseline value, cohort (normal and stroke), age, gender, strength(Y/N), Posture Re-ed (Y/N) and Strength by Posture Re-ed interaction. Marginal means are calculated using the mean baseline values in the study population. The frequency is expressed as cycles per hour in order to make the data more meaningful. Each cycle represents an angular movement > 5°.

N=69 (combined normal and stroke cohorts)

9.3.6.4. The group effects

Age and, to a lesser extent, gender, had a significant effect on change in kyphotic angle over the 12 weeks.

The marginal means of the differences between baseline and 12 week FEG angle significantly decreased with increasing age for upright standing FEG angle ($p = 0.004$), walking FEG angle ($p = 0.002$) and deep breathing FEG angle ($p < 0.001$) (Figure 9.9). Although the 6hr FEG measurements were not significantly affected by age, there was a similar trend. The marginal means for the 6hr FEG angle are shown in Figure 9.9 to illustrate the trend even though the differences were not significant.

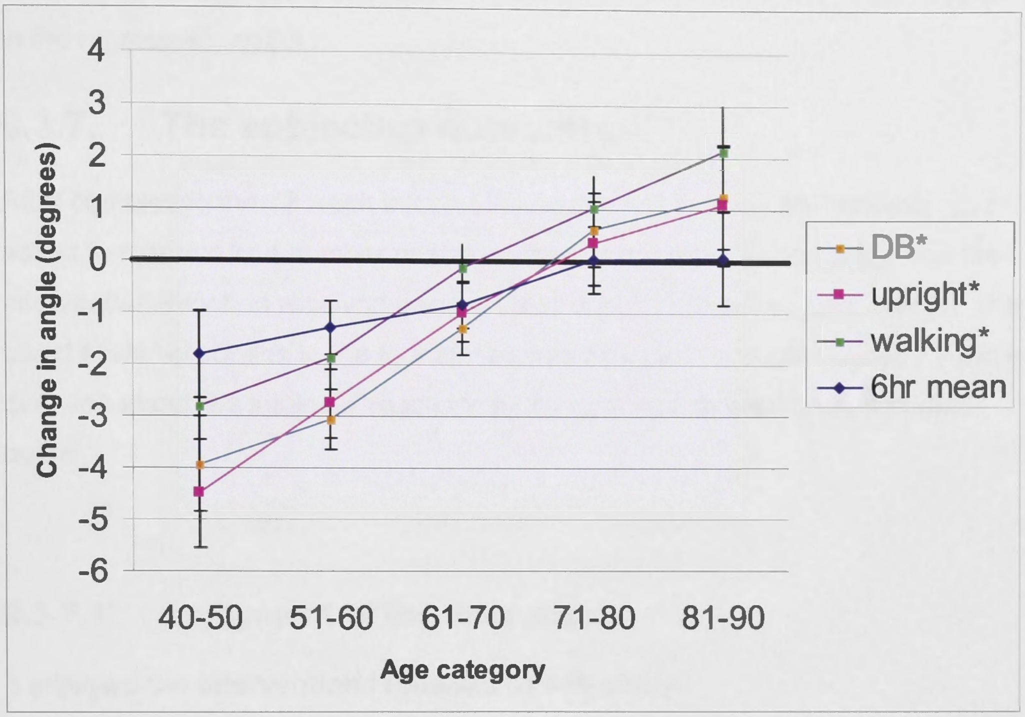

Figure 9.9. The marginal means of the differences in FEG angle between baseline and 12 week measurements by age category. Increasing age resulted in decreased reduction in thoracic angle.

Note. Negative angle values indicate a reduction in kyphosis. The error bars represent ± standard errors for the marginal means. The marginal means and associated standard errors are based upon a linear model, adjusting for baseline value, cohort (normal and stroke), age, gender, BMI and intervention. Marginal means are calculated using the mean baseline values in the study population. *significant effect due to age $p<0.005$

The females demonstrated a significant reduction in FEG angle compared to the males for walking ($p = 0.025$) and deep breathing ($p = 0.004$). For the deep breathing measurement the marginal mean of the differences for the females was -2.6° ± 0.6° while in males it was 0.3° ± 0.7°. For walking the marginal mean of the differences for the females was -1.4° ± 0.5° and for males 0.9° ± 0.7°. Although not significant, this trend was also seen in all of the other angular measurements except for 6hr mode.

There were no significant effects due to cohort (normal or stroke) or BMI detected in the regression model.

9.3.7. The subjective outcomes

After completing the 12 week intervention phase of the study the subjects were asked to respond to a number of statements about how they had perceived the intervention they had received using a Likert 6 point scale (see appendix E). The Likert scale responses to the four statements as well as a supplementary yes/no question about the subjects' reactions to the gym environment are presented below.

9.3.7.1. Enjoyment of the intervention

'I enjoyed the intervention I received in this study.'

The subjects in the BOTH group were the most positive about their experience with 69% strongly agreeing that they had enjoyed the intervention. However, when both agreed and strongly agreed were considered together the subjects in the STR group were similarly positive. Two of the PED subjects were undecided as to whether they enjoyed the intervention and one of the subjects in the BOTH group did not enjoy the experience. The CON group primarily responded that the question was 'not applicable' but notably, five of the CON subjects said that they had enjoyed the intervention even though they had not received any. A summary of the responses to this statement are shown in Figure 9.10.

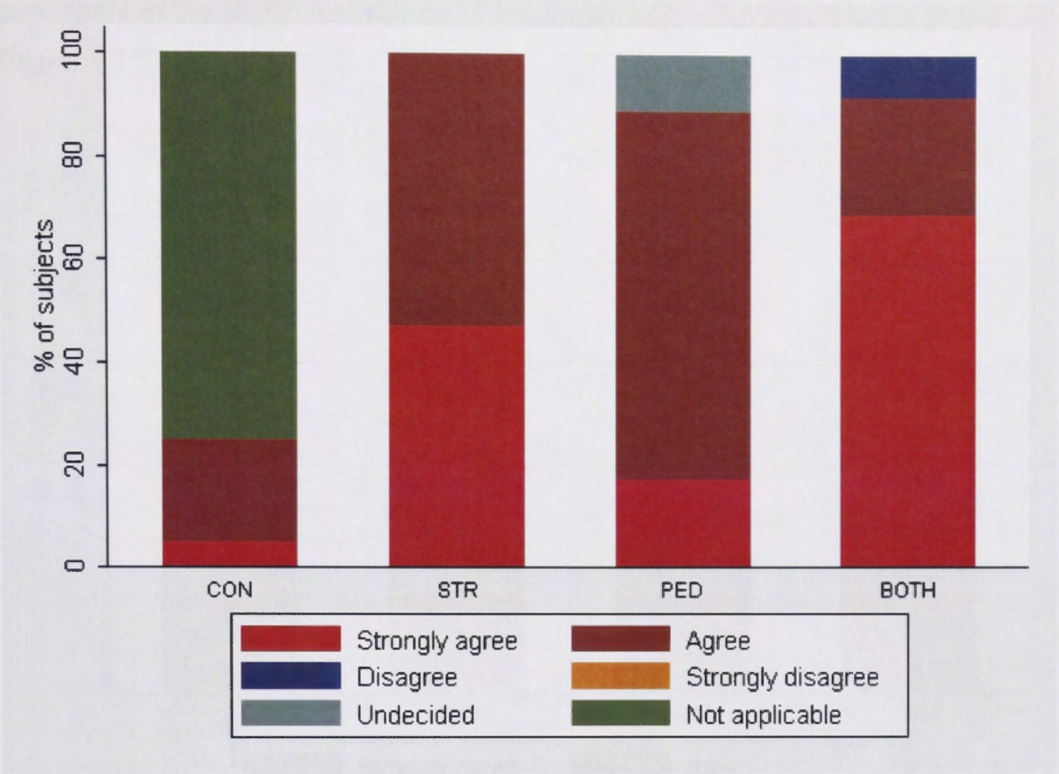

Figure 9.10 Degree to which the subjects enjoyed the intervention by intervention group.

Note. The data are expressed as the percentage of the number of subjects in the individual intervention group. N=69 combined normal and stroke cohort. CON = control, STR = strengthening only, PED = postural re-education only, BOTH = strengthening and postural re-education.

9.3.7.2. Improvement in posture

'I believe that my posture has improved after having been in the study.'

The subjects BOTH group were the most convinced that their posture had improved with 31% agreeing strongly. The STR group were more positive about an improvement in their posture than the PED group, with more of the PED subjects responding that they were undecided as to whether it had improved or not. One CON group subject felt that their posture had improved as a result of being a participant in the study. A summary of the responses to this statement is shown in Figure 9.11.

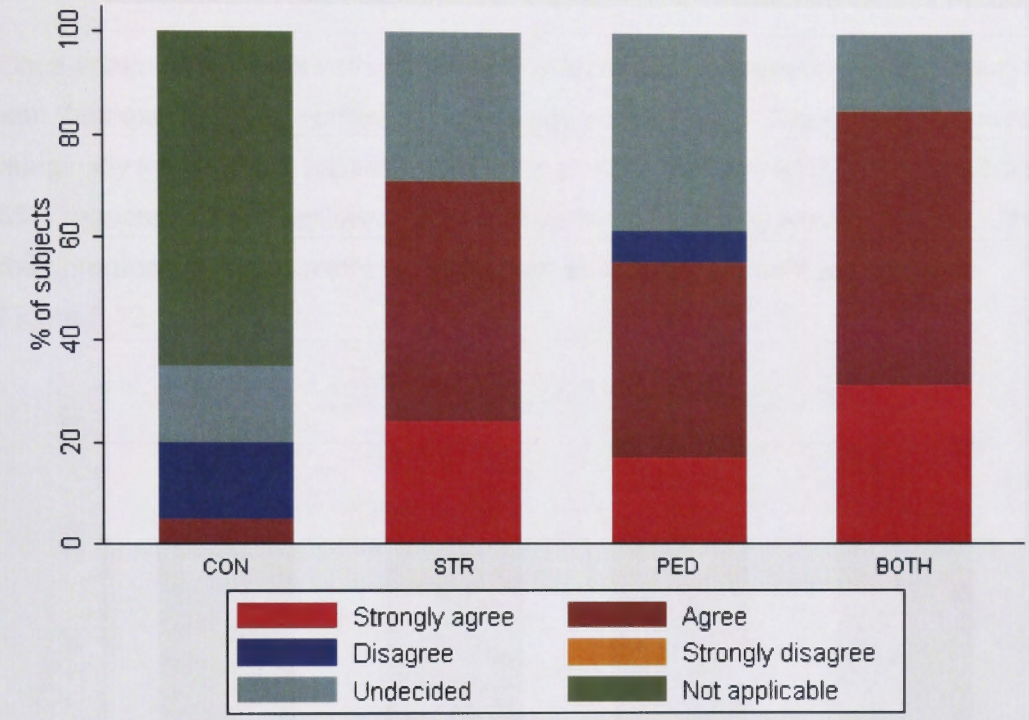

Figure 9.11 Degree to which the subjects believed their posture had changed as a result of the intervention

Note. The data are expressed as the percentage of the number of subjects in the individual intervention group. N=69 combined normal and stroke cohort. CON = control, STR = strengthening only, PED = postural re-education only, BOTH = strengthening and postural re-education.

9.3.7.3. Continuation of the exercise programme

'I will continue to do what I have been doing for the study as part of my everyday life.'

Once again the subjects in the BOTH group were more positive about continuing with their exercise programme after the study period ended. The PED group were marginally less positive but they were more positive than the STR group, of whom 53% responded that they were undecided as to whether they would continue with their programme. A summary of the responses to this statement are shown in Figure 9.12.

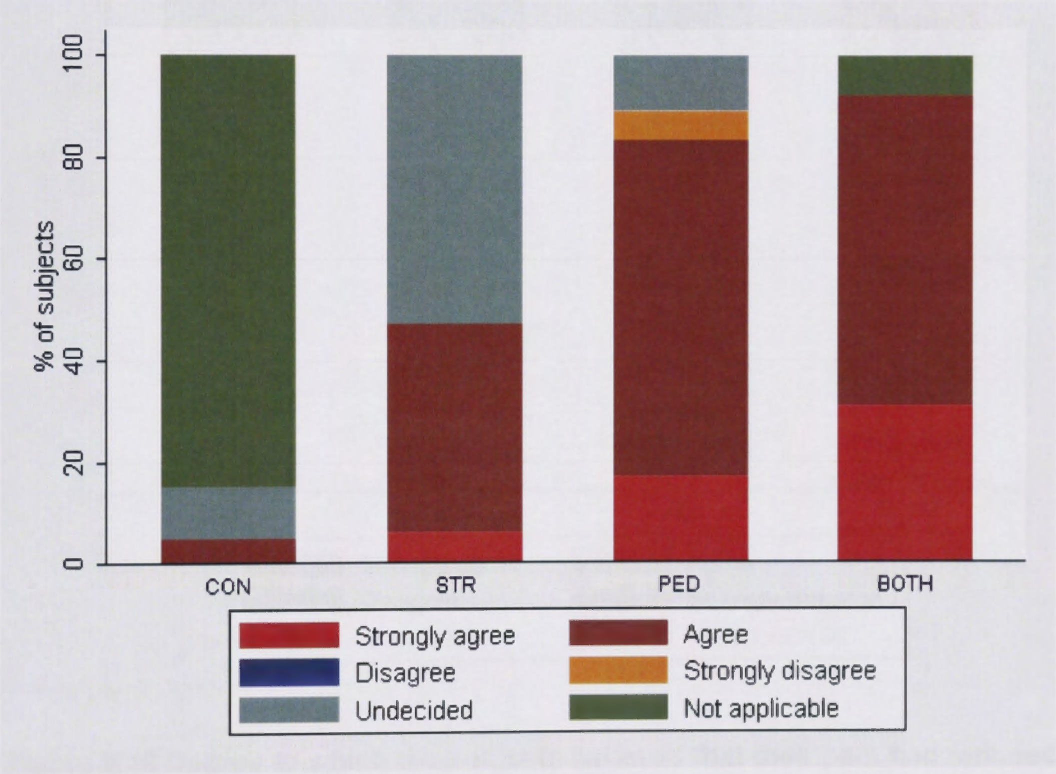

Figure 9.12 Degree to which the subjects believed that they would continue to do the intervention exercise after the completion of the study.

Note. The data are expressed as the percentage of the number of subjects in the individual intervention group. N=69 combined normal and stroke cohort. CON = control, STR = strengthening only, PED = postural re-education only, BOTH = strengthening and postural re-education.

9.3.7.4. Pain reduction

'My pain has reduced as a result of doing the programme.'

More of the PED subjects answered positively to this question than the other intervention groups. Most of the subjects indicated that their pain had either not changed or that they didn't have pain at baseline. A summary of the responses to this statement are shown in Figure 9.13.

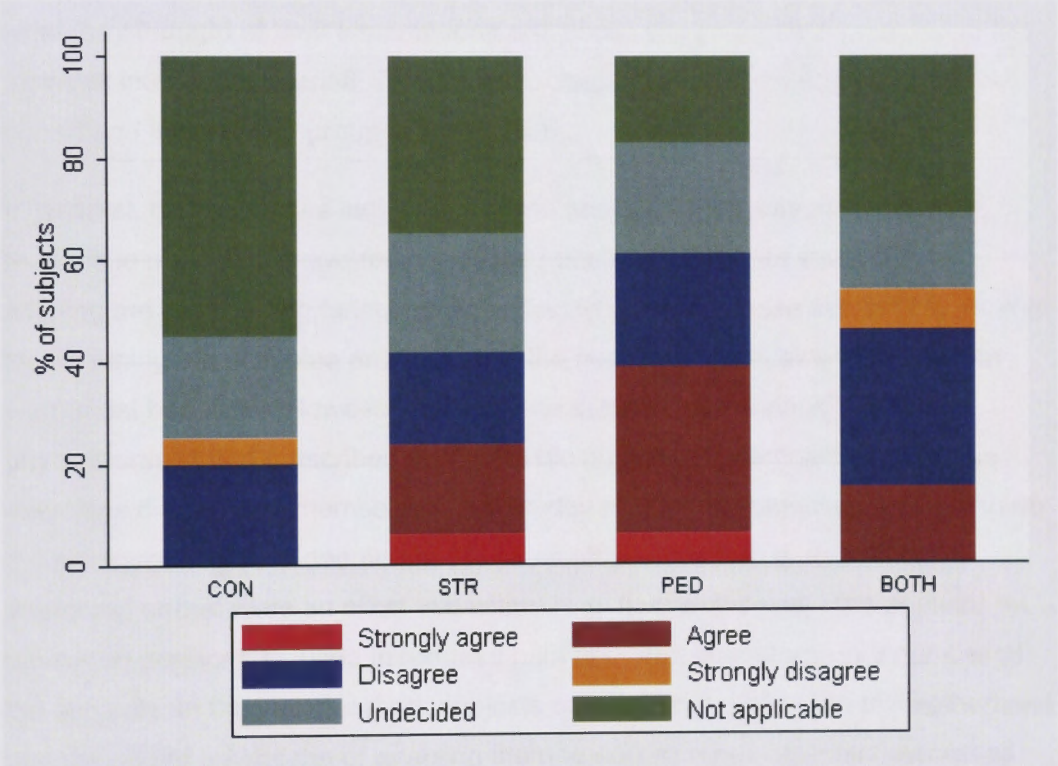

Figure 9.13 Degree to which the subjects believed that their pain had reduced as a result of the intervention.

Note. The data are expressed as the percentage of the number of subjects in the individual intervention group. N=69 combined normal and stroke cohort. CON = control, STR = strengthening only, PED = postural re-education only, BOTH = strengthening and postural re-education.

9.3.7.5. Attitude to attending a gym

The subjects who attended a gym for strengthening (STR and BOTH) were asked whether being part of the study had demystified the gym environment for them. Of the 32 subjects who attended the gym as part of the study, 13 said that being part of the study had 'demystified' gyms for them; 5 replied that it had not; and 14 replied 'not applicable' because they had previously attended a gym.

9.3.7.6. Responses to the exit questions

In addition to filling out the questionnaire, the subjects were asked to elaborate on what they thought of their interventions and about any changes in pain during the 12 week intervention period. The individual responses are listed by pathological cohort and intervention group in appendix F.

In general, the responses indicated that the postural re-education intervention resulted in much better awareness of body position and better strategies for aligning the body during functional activities. In particular these subjects found that repositioning the scapulae and adjusting the neck into a less extended position were most beneficial. However, some of the subjects complained that the physiotherapist had prescribed an unrealistic number of exercises and that the exercises did not lend themselves to everyday life. Some subjects chose not to do the exercises that they deemed not to be directly relevant (e.g. quadriceps stretches) or that were an effort to perform (e.g. floor exercises). The postural re-education sessions resulted in reduced pain and other symptoms in a number of the subjects. In the stroke cohort, subjects reported that seeing the physiotherapist had the added advantage of enabling them to access other important resources such as the falls clinic.

The STR subjects were generally more positive about the experience than the BOTH subjects. Getting to the gym and parking was seen as involving considerable effort in the normal group but not in the stroke group. The subjects felt stronger in the trunk in general and some commented that they felt taller and lighter after their sessions. However, one subject commented that when they incremented their resistance weight too much, the usual effect of feeling taller was lost (appendix F4, N57).

9.3.8. The relationships between the variables

The response variables were grouped into the kyphosis angles, the physical ability measurements, the movement frequencies and the pain measurements (9.3.4.1, 9.3.4.2, 9.3.4.3 and 9.3.4.4). In this section the relationships between some of the individual response variables and the groups of variables are explored.

9.3.8.1. The baseline thoracic angle response variables

All of the baseline FEG angle measurements were strongly and significantly correlated with each other ($p < 0.00001$) (Table 9.14). The FEG angles were either static or dynamic. The mean and the mode FEG angles were dynamic measurements which summarised the kyphotic angle over the 6 hour day. The mean FEG angle was correlated more strongly than the mode with the individual static FEG angles ($r = 0.82 – 0.92$ vs $0.78 – 0.89$) (Table 9.14). The mean FEG angle measurement correlated most strongly with the static measurements of walking ($r = 0.92$) and relaxed standing ($r = 0.90$). The static measurements all correlated very strongly with each other with the exception of toe touching ($r = 0.69 – 0.82$) Table 9.14. After 6hr mean and mode ($r = 0.97$) the most highly correlated measures were walking and relaxed standing ($r = 0.96$). The FEG angles for upright standing, reaching for the ceiling and deep breathing were all very highly correlated ($r > 0.94$).

The inclinometer angles, which were measures of the kyphotic angle between T1 and T12, were significantly ($p < 0.00001$), but only moderately, well correlated with their corresponding FEG angles. Although the upright standing inclinometer measurements correlated most strongly with the upright standing FEG measurements ($r = 0.69$), the relaxed standing inclinometer measurements correlated more strongly with the 6hr mean FEG angle and walking FEG angle ($r = 0.68$) than with the relaxed standing FEG angle ($r = 0.64$).

Table 9.14

FEG angle measurement correlations

		Dynamic (6hr)				Static					
		Mean	Mode	Max	Min	Relaxed	Upright	Ceiling	Toes	Walking	DB
Dynamic (6hr)	Mean	1	0.97	0.88	0.90	0.90	0.88	0.89	0.82	0.92	0.88
	Mode		1	0.85	0.87	0.89	0.86	0.86	0.78	0.89	0.84
	Max			1	0.74	0.80	0.81	0.79	0.69	0.84	0.80
	Min				1	0.82	0.84	0.82	0.76	0.84	0.81
Static	Relaxed					1	0.94	0.92	0.72	0.96	0.91
	Upright						1	0.94	0.72	0.95	0.94
	Ceiling							1	0.76	0.94	0.95
	Toes								1	0.78	0.76
	Walking									1	0.94
	DB										1

Note. Pearsons r correlation values are shown. All of the correlations were highly significant ($p < 0.00001$). The r values which were > 0.90 (excellent) are shaded in grey. The correlations between the dynamic and static measurements are contained within the box marked with a dotted line. The Mean 6hr measurement was highly correlated with both the walking and relaxed standing static measurement.

9.3.8.2. The physical ability response variables

The measurements of physical ability did not all correlate with each other. The physical ability measurements included the 10 metre walk test, the timed up and go test, the stair test and the X5 sit to stand test as well as chest expansion, the back extension strength tests and physical activity score (Table 9.15). The timed tests correlated very strongly with each other and the 10 metre walk test and the timed up and go were the most strongly correlated ($r = 0.97$, $p < 0.00001$). The back extensor strength measures correlated strongly with each other ($r = 0.82$, $p < 0.00001$) and, to a lesser extent, with chest expansion, the stair test and the X5 sit to stand test ($p < 0.05$) but not with the 10 metre walk test and the timed up and go. Apart from the strength measures, chest expansion was significantly correlated with X5 sit to stand only ($p = 0.03$). The physical activity score was not significantly correlated with any of the physical ability tests.

Table 9.15

Correlation matrix for the physical ability measurements

	10m WT	TUAG	ST	X5 STS	CE	Myo	N. Myo	PAS
10m WT	1							
TUAG	0.97*	1.00						
ST	0.78*	0.85*	1.00					
X5 STS	0.79*	0.85*	0.64*	1.00				
CE	-0.21	-0.18	-0.31*	-0.26*	1.00			
BES	-0.21	-0.14	-0.24*	-0.24*	0.38*	1.00		
N.BES	-0.22	-0.19	-0.37*	-0.31*	0.36*	0.82*	1.00	
PAS	0.02	-0.03	-0.18	-0.14	0.24	-0.18	-0.05	1.00

Note. Pearson correlation co-efficients. * = significant $p < 0.05$. Timed tests are shaded grey. 10m WT= 10m walk test; TUAG = timed up and go; Stairs = stair test; X5 STS= X5 sit to stand; CE = chest expansion; BES = back extensor strength; N.BES = BES normalised by weight; PAS= physical activity score.

9.3.8.3. The relationship between baseline thoracic angle, physical function, strength and movement frequency

The relationships between the response variables were simplified using a principal component analysis in order to determine if any underlying dimensions, or themes, emerged. The variables which influenced the model most were the ones which measured the maximum extension of the thoracic spine, the 6hr sagittal movement frequency, the timed physical ability measures and the normalised BES. Two principal factors were identified (eigenvalues 5.0 and 2.6[*]) which, after rotation, explained 76% of the data. The first factor, which explained 50% of the data, was associated with measures of thoracic angle and 6hr sagittal movement frequency. Subjects with increased kyphosis tended to have decreased 6hr sagittal movement frequency. The second factor, which explained 26% of the data, was associated with the normalised BES measure and the timed physical ability tasks. Subjects with increased strength were able to complete their timed tasks more quickly. The loading plot which illustrates these relationships is shown in Figure 9.14.

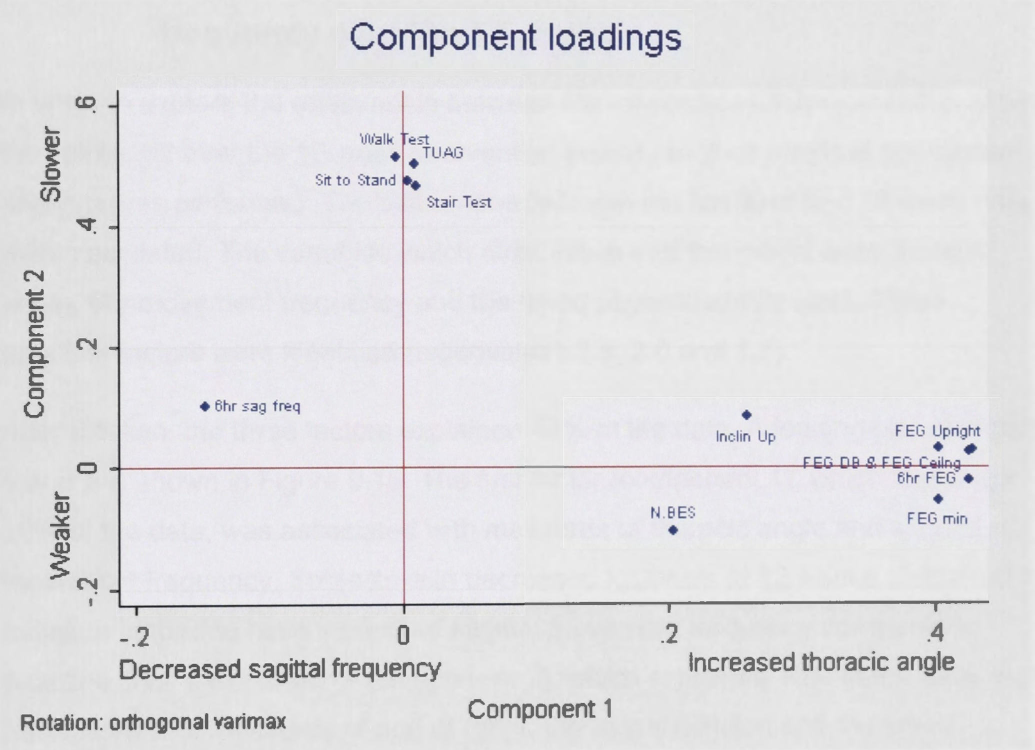

Figure 9.14 Loading plot of factors 1 and 2 for the principal component analysis of representative baseline variables. The plot indicates reciprocity between thoracic angle and 6hr sagittal movement frequency, and time to complete a task and strength.

Note. 6hr sag freq = rate of sagittal movement over 6hr recording; N.BES = normalized myometry.

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[*] Eigenvalues describe the variance explained by each discriminant function.

Subsequent testing of these associations indicated that, of all the FEG angles included in the principal component analysis, upright standing FEG angle correlated most strongly with 6hr sagittal frequency (-0.46, p = 0.0001). Of all the timed tests, stair test time and the X5 sit to stand time were the response variables which were significantly related to normalised BES (-0.37, p = 0.01 and -0.31, p=0.01 respectively) (Table 9.15).

9.3.8.4. The relationship between the differences in thoracic angle, physical function, strength and movement frequency over the 12 weeks

In order to explore the relationship between the response variables in terms of how they changed over the 12 week intervention period, another principal component analysis was performed. The differences between the baseline and 12 week data were calculated. The variables which most influenced the model were thoracic angle, 6hr movement frequency and the timed physical ablility tests. Three principal factors were identified (eigenvalues 2.5, 2.0 and 1.7).

After rotation, the three factors explained 48% of the data. A loading plot of factors 1 and 2 is shown in Figure 9.15. The first factor (component 1), which explained 20% of the data, was associated with measures of thoracic angle and sagittal movement frequency. Subjects with decreased kyphosis at 12 weeks compared to baseline tended to have increased sagittal movement frequency compared to baseline. The second factor (component 2), which explained 15% of the data, was associated with measures of end of range thoracic extension and the timed physical ability measures. Subjects whose minimum extension angle was smaller at 12 weeks than at baseline (i.e. more extended), tended to be faster in their physical ability tests. The third factor which is not shown in Figure 9.15, explained 13% of the data and was associated with the 6hr sagittal movement frequency and the 6hr mean FEG angle. Subjects who had an increase in movement frequency over the 12 weeks tended to also demonstrate a decrease in 6hr mean FEG angle compared to baseline.

Subsequent testing of these associations showed that the effects seen in factor 1 and 3 were primarily influenced by the correlation between 6hr movement frequency and 6hr FEG measurement (r = - 0.31, p=0.009). The effect seen in factor 2 was primarily influenced by the correlations between 6hr minimum FEG angle and both the timed up and go (r = - 0.34, p = 0.004) and the 10 m walk test (r = - 0.34, p = 0.005).

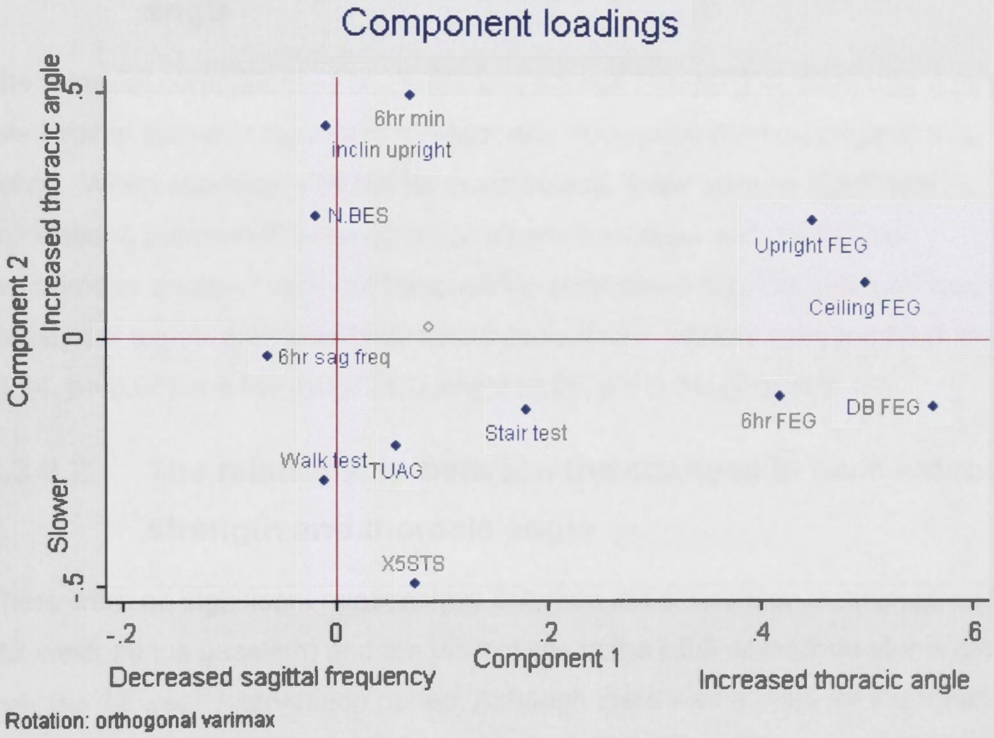

Figure 9.15 Loading plot of factors 1 and 2 for the principal component analysis of the differences between baseline and 12 week measurements of representative variables.

Note. 6hr sag freq = rate of 6hr sagittal movement; N.BES= normalised myometry; x5STS = timed X5 sit-to-stand test. Walk test = 10m walk test

9.3.9. The effect of back extensor strength on thoracic angle

The relationship between the FEG angles and BES were analysed in terms of baseline values and also the changes over the 12 week intervention period.

9.3.9.1. The relationship between baseline strength and thoracic angle

The principal component analysis (above) did not indicate that there was a strong relationship between increased strength and decreased thoracic angle in this cohort. When specifically tested for associations, there were no significant correlations between the raw baseline myometry values and the FEG or inclinometer angles. However, the baseline normalised myometry values were weakly but significantly positively correlated with the relaxed standing FEG angle (0.24, $p= 0.04$) and toe touch FEG angle (0.25, $p = 0.04$) (Figure 9.16).

9.3.9.2. The relationship between the changes in back extensor strength and thoracic angle

There were no significant relationships between the differences in normalised BES (12 week minus baseline) and the differences in the FEG or inclinometer angles over the 12 week intervention period. Although there was a trend for the mean 6hr FEG angle to decrease (back to be held more straight) with an increase in normalised BES (Figure 9.17), none of the components of the linear regression model, which also included group, gender and age, was significant

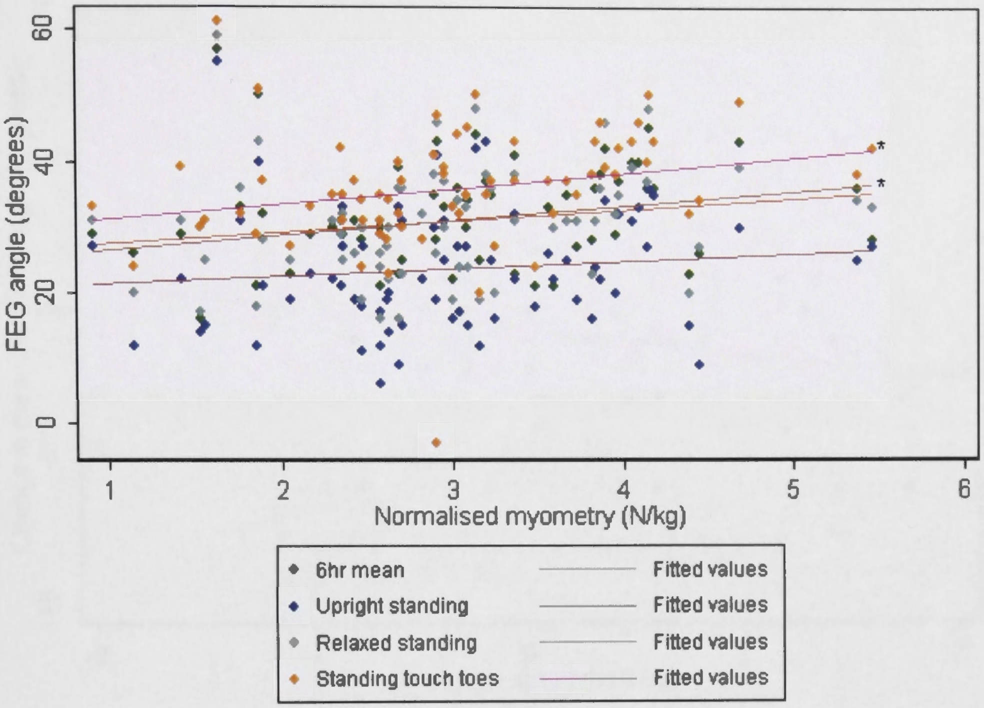

Figure 9.16 Scatterplot of baseline normalised myometry vs baseline FEG angle for four different activities. All FEG angles are positively correlated with the normalised myometry values but only the correlations with relaxed standing and standing touch toes are significant.

*Note.** significantly correlated p <0.05

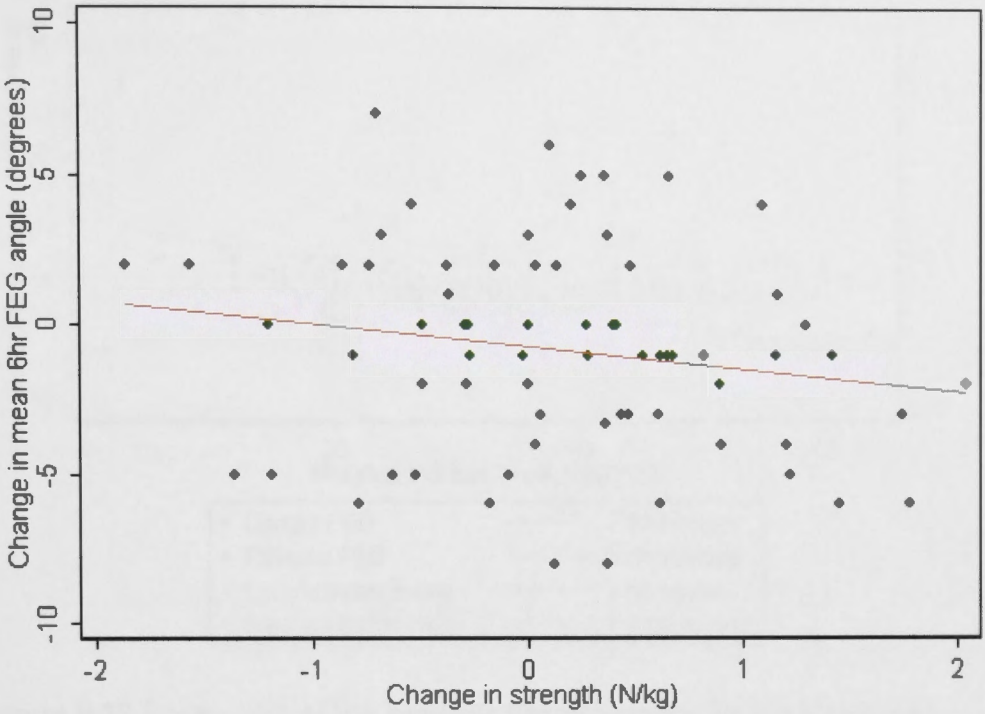

Figure 9.17 Scatterplot of the difference in normalised myometry by the difference in the mean 6hr FEG angle.

Note. The data include all of the subjects from both the normal and stroke cohorts. More negative changes in FEG angle and more positive values of strength indicate improvement. The dashed line is the best linear fit for the data.

9.3.10. The relationship between baseline thoracic angle and change in thoracic angle

The baseline inclinometer measurements were better predictors of change in thoracic angle over the 12 weeks than the FEG angle measurements. The baseline FEG angles were not significantly correlated with change in angle but the inclinometer angles were (upright inclinometer r = -0.47, p = 0.0001; relaxed -0.36, p = 0.004, Figure 9.18). The data from the inclinometer measurements indicated that subjects with larger kyphotic angles at baseline reduced their kyphosis more over the 12 weeks than subjects with smaller kyphotic angles.

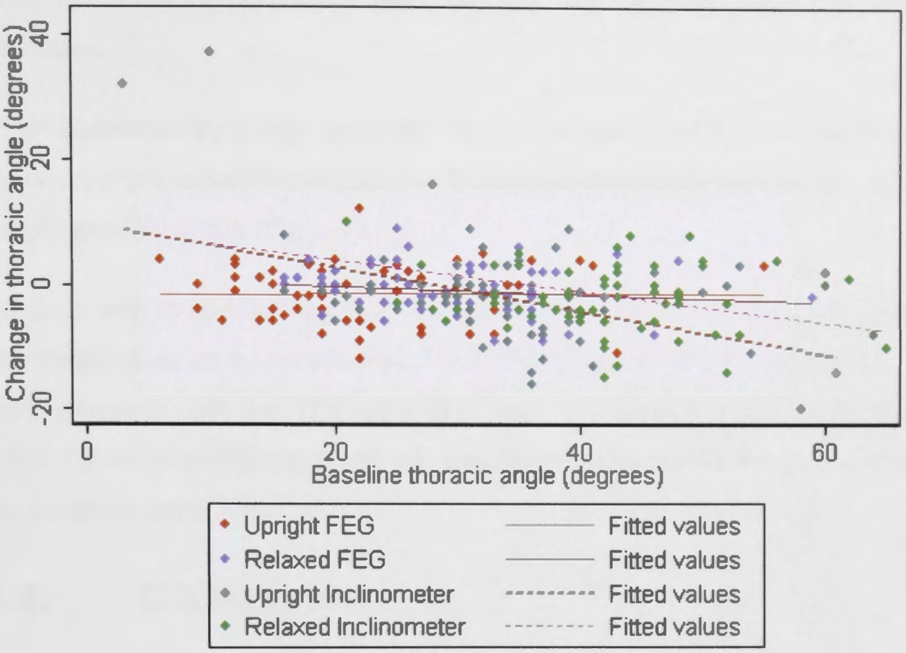

Figure 9.18 Scatterplot of the baseline thoracic angle by the change in thoracic angle for the upright and relaxed FEG and inclinometer angles.

Note. The data include all of the subjects from both the normal and stroke cohorts. More negative changes in angle indicate a decrease in thoracic angle. The lines indicate the best linear fit for each dataset.

9.3.10.1. Summary of the results

There were relatively few significant differences between the intervention groups but, overall, the BOTH group appeared to be the most consistent in terms of a trend towards improvement in thoracic angle. The physical function outcomes were most improved in the STR group. There were no significant differences between the intervention groups and the CON group in terms of change in the movement frequency (positive or negative). The subjects in the BOTH group enjoyed the experience most, perceived that their posture had improved most, and were more positive about continuing their exercise programme after completing the study. However, the STR group was more positive about the intervention they received than the PED group. The PED group believed that their pain had reduced most as a result of the intervention but this effect was not demonstrated in the VAS measures.

When examined by group, age had the most effect on how much the angle changed with a clear deterioration in the potential for change due to intervention in people over 70 years (Figure 9.9).

Subjects with increased kyphosis moved less frequently in the sagittal plane. This association was demonstrated both at baseline and in the change in the measurements over the 12 weeks. BES was only weakly related to thoracic angle in this cohort but BES predicted the time taken to complete the stair climb test and the X5 sit to stand test.

9.4. Discussion

The aims of the study were listed in 9.1.1.

There were seven main findings from this study. First, there was a trend for the BOTH group to perform better in terms of a decrease in kyphosis, but the STR group performed significantly better in the measures of physical ability. Second, there were no significant differences between the normal and the stroke cohorts in terms of response to the interventions for any of the response variables. Third, age limited the potential for change in kyphotic angle with a profound limitation in subjects older than approximately 70 years of age. Fourth, movement frequency in the thoracic spine was very low and the frequency in the sagittal plane was approximately half that in the coronal plane. Fifth, larger kyphotic angles were significantly associated with decreased sagittal plane movement frequencies at baseline and reductions in kyphosis over the intervention period were associated with an increase in movement frequency. Sixth there was a significant association between baseline kyphosis and change in kyphotic angle for inclinometer measurements between T1 andT12 but not for the FEG measurements which did not include the upper thoracic spine. Finally, although greater back extensor strength (BES) was weakly associated with lower baseline relaxed standing angles, increased BES over the 12 weeks was not significantly related to decreased thoracic angle in this cohort of non-osteoporotic men and women.

9.4.1. The effect of the interventions

9.4.1.1. The thoracic angles

In this study the angular changes after 12 weeks, regardless of the intervention group, were modest. The BOTH group demonstrated larger improvements for more of the FEG measures than any of the other groups, while the STR group improved most in the inclinometer measurements. The PED group improved most for the walking FEG angle but the marginal mean of the difference was just 1.1°. None of the measures which aimed to detect a decrease in kyphosis reached significance. The lack of statistical significance may imply that the differences detected were just random noise but the fact that several of the outcome measures trended in the same direction suggests that real differences may have been missed because the subject numbers were too small.

The FEG did not measure the entire thoracic spine between T1 to T12 but covered a section of the spine which was 24 cm long centred on the T6/7 interspinous space. The section of the spine measured varied in terms of spinal levels, but in over 87% of the subjects the section measured was between T3 and T10 or T11. On the other hand, the inclinometer measured between T1 and T12 and so included the uppermost thoracic vertebrae as well as T11 and T12. The baseline angles measured were between 10° (upright) and 12° (relaxed) greater for the inclinometer than they were for the FEG (Table 9.6). Therefore, the greater relative differences in the inclinometer measurements compared to the FEG measurements may reflect a larger relative change in the upper thoracic spine. In the kinematic study (chapter 7) it was noted that the upper thoracic and lower cervical spine became straighter and less lordosed during sitting with scapular retraction (Figure 7.3). So, the comparatively large decreases in inclinometer angle in the STR group may have reflected a change in the upper thoracic spine which did not occur to the same extent in the other intervention groups. It is worth noting that the BOTH group also demonstrated larger angular reductions compared to the PED and the CON groups.

Forward head posture (FHP) is described as excessive anterior positioning of the head in relation to a vertical reference line, involving increased cervical spine lordosis (head forward, middle cervical spine extended, lower cervical spine flexed) [475]. Some authors have reported a strong relationship between FHP and thoracic hyperkyphosis [6, 97, 475] but a large descriptive study found otherwise [368]. The fact that the vertebrae above T4 are functionally more associated with the cervical spine than they are with the thoracic spine [109] supports the existence of a relationship, as does the fact that significant differences between kyphotic angle measurements have been reported depending on how many, and which, levels are measured (chapter 2, Table 2.1). Also, recent *in vitro* studies of the spine showed that, in cadaveric preparations, the region between T1 and T4 has the greatest ROM and the least stiffness [151]. Therefore, a possible explanation for the finding that the strengthening intervention significantly reduced the T1 – T12 kyphotic angle but not the T3 – T10/11 kyphotic angle may have been that it was very effective at decreasing FHP with extension of the upper thoracic spine; whereas it was less effective at reducing kyphosis in other thoracic regions including the apex.

The angular differences reported in this study were controlled for age, gender and cohort and, although the marginal means did not reach statistical significance, they were comparable to the angular changes reported in two previous studies which reported significant improvement in thoracic angle after conservative exercise-based interventions [8, 9]. Greendale et al. (2009) reported the differences between baseline and the post-intervention measurement as a percentage change. Their 3° change in T1 to T12 kyphometer angle after a 12 week yoga intervention represented a 5.2% change. Katzman et al. (2007) reported a larger angular change after a multidimensional exercise programme of 6° (upright) and 5° (relaxed) which represented a 10.5% and 10% change. In this study, a 4.1° change in upright inclinometer angle represented a 12% change; and the 3.6° change in relaxed standing inclinometer angle represented an 8% change. When considered as a percentage, the data are comparable because the mean baseline thoracic angle of the subjects in this study was smaller than in both the Katzman and the Greendale studies. In this study the mean relaxed standing inclinometer (T1-T12) angle was 43.1° while in the other studies the angles were 57° and 58° respectively.

It has been suggested that the extent to which the kyphotic angle can be reduced is relatively increased when the subject is more kyphosed in the first place [10] [96]. In this study there was a significant association between baseline kyphosis and change in kyphotic angle measured with the inclinometer between T1 and T12. However, there were no significant associations found between baseline values and changes in the FEG angles (Figure 9.18). These data support suggestions made by other authors that the degree of baseline kyphosis influences the potential for angular change [10] [96]. This may also explain why the differences were marginally smaller in the cohort of the current study compared to those described above. However, an alternative explanation may be that the inclinometer was inherently a more variable instrument and the changes seen represented a regression to the mean [629].

The results of this study suggest that the most changeable part of the thoracic spine in people with excessive kyphosis may be the upper thoracic spine, although the possibility that changes in the lower two levels may also be important cannot be ruled out. The upper, middle and lower sections are anatomically different in terms of their rib articulations and anterior attachments as discussed in chapter 2. It is possible that the action of the middle fibres of the trapezius, which potentially have a significant effect on the stability of the upright spine (chapter 2, 2.3.12.6, 2.4.3.1) and were deliberately activated in the thoracic extension exercise used in this study (chapters 7 and 8), may be responsible for the maximal effect on the upper thoracic spine. The design of a future study would benefit from separating the regions of the thoracic spine so as to differentiate between them.

9.4.1.2. Physical ability

Strengthening resulted in better results on physical function tests than did postural re-education. The times for the 10 metre walk and the X5 sit to stand test were both significantly decreased in the strengthening only group, and the group which received both interventions showed the largest reductions in the stair-test time. Two other studies also evaluated physical function after an intervention to decrease thoracic kyphosis [8, 9]. Neither reported an increase in walking velocity and although the yoga intervention group demonstrated a reduction in X5 sit to stand time it was not significantly different from the control [9]. Therefore the strengthening intervention used in this study stands out in terms of improvement in physical function.

Significant strengthening only occurred in the STR group. The STR group increased their back extensor strength (BES) by 32N which represents a change in BES above the minimal difference (MD) of 20.7N (chapter 8). However, only when normalised by weight was BES significantly greater. The MD threshold was, however, not achieved in the BOTH group and the PED group registered a zero mean change in BES even though they had all been given a home programme designed to improve postural strength and awareness. One explanation for this disparity may be that the strengthening test was a static version of the strengthening exercise performed by the strengthening group so it is perhaps no surprise that the subjects who had practiced this exercise were better at it. What was a surprise was that the BOTH group did not improve significantly. The STR group attended only 5% more gym sessions than the BOTH group so this is unlikely to explain such a marked difference in outcome. It is possible that the effect of the gym was somehow diluted by the addition of the home exercise regimen associated with the postural re-education intervention. The subjects may have become physically or psychologically 'fatigued' by the burden of this level of therapeutic exercise but this is merely speculation since there is no data which specifically supports this theory.

9.4.1.3. Pain

None of the intervention groups showed a clinically significant difference in their level of pain. The VAS scores for pain in this cohort were low with mean scores of < 20/100. The range of scores, however, was high with some scores greater than 80/100. The effect of the interventions on the VAS scores was minimal with none of the differences surpassing the minimum clinical significant difference (MCSD) of 11mm (11/100) for mild pain or 10mm (10/100) for severe pain [626].Other studies which have measured changes in pain after interventions for thoracic hyperkyphosis have also reported no significant differences in pain scores [96, 424].

9.4.1.4. The subjective outcomes

The subjective responses from the subjects in this study most positively supported the strengthening intervention, but only in the short term. The questionnaire results revealed that the subjects in the BOTH group enjoyed their experience most and were more certain that their posture had improved as a result of the intervention (Figure 9.10 and Figure 9.11). The STR group were more positive than the PED group about both enjoyment and certainty of postural improvement (Figure 9.10 and Figure 9.11). However, the subjects who went to the gym were less certain that they would continue with their exercises than those who had been taught to do postural exercises at home (Figure 9.12). As well as the Likert-type question format of the questionnaires, all of the subjects were asked to express their opinions more freely in the exit interview (appendix F). Most of the subjects who attended the gym felt stronger and more upright but only a few expressed a desire to continue. The effort of finding a parking space and the effort of going at all were the two barriers to continued gym use which were most often expressed. Although the Likert questionnaires indicated that the PED group was less positive about their intervention than the STR group, in the free responses the subjects in the groups that received postural re-education were very positive (appendix F2 and F3). One subject remarked that she wouldn't have seen a physio unless she had pain in the past but she had really noticed a change from the postural exercises (appendix F3, N25). Subjects were most positive about the exercises which focused on their scapular and neck position and some reported that if too many exercises were prescribed they either didn't do them or just did the ones they felt were directly useful (appendix F3, N53 and N60). An interesting example which was given was by a subject who was asked to do hamstring stretches to help correct his posture. The subject did not detect any direct relevance and chose to abandon them after less than a week yet continued to do the scapular retraction exercises because they made him feel better (appendix F3, N60). Another interesting comment was that the position in which the exercise was performed needed to be in standing or sitting to facilitate compliance (appendix F2, N59). Lying down during the day was not seen as feasible for working people but was more acceptable to people who did not work.

Some of the subjects who went to the gym described a sense of feeling lighter and taller after doing their exercises, but one subject commented that if he increased the resistance weight used too much, the opposite happened and he felt less tall (appendix F4, N57). In chapter 2 and chapter 7 the concept of the thoracic spine assuming an arched configuration in response to significant load was discussed. It is interesting to speculate that the subject in this study may have been describing this phenomenon. According to the proposed theory, the addition of too much weight would have necessitated a change in musculoskeletal strategy, so that the abdominals were recruited to pull the thoracic spine into a stable arch. In this situation extension would have been achieved by rotation at the lumbar spine. Conversely, if the load was correct he would have been able to complete the task by extending his thoracic spine, thereby recruiting his thoracic erector spinae muscles which, in turn, resulted in a feeling of being taller. The amount of resistance used in this study was based on the results of a meta-analysis which recommended a 'dose' of 60% of 1RM which was determined to be the best resistance for untrained individuals [602]. This level of resistance was, however, a generalisation and was not specifically tested as giving rise to the best response from the thoracic extensors. A previous study of the comparative effect of high and low resistance programmes in older people found that 50% of 1RM was similar in effectiveness to 80% of 1 RM and concluded that there was little to be gained from using the higher resistance [630]. It is therefore possible that the resistance of 60% of 1RM was too high for the thoracic extensors and a lower resistance should have been used. Also, responsibility for the maintenance of this resistance was given to each individual subject so it is possible that some may have inadvertently 'overdosed' themselves leading to a flexion response rather than extension. This could be the basis of an interesting EMG study in the future.

9.4.2. The stroke group

The stroke group were included in this study in order to discover whether thoracic kyphosis could be reduced in people with stroke and whether physical function was improved as a result. The baseline data indicated that the stroke subjects were more kyphosed than the normal group for most angle measurements but only by approximately 2°. They were, however, considerably slower at the timed functional tests and their spinal movement frequency was lower being approximately 80% of the frequency measured in the normal group (Table 9.8). The baseline BES measurements were reduced in the stroke subjects compared to the normal subjects as has been previously reported [513]. The regression analyses, however, showed that whether a subject had had a stroke or not did not affect their outcome in terms of any of the response variables. This meant that the people in the stroke cohort responded to the interventions in the same way as the normal subjects. None of the stroke subjects reported any ill effects from participating in the strengthening group, in fact those who did, were very positive (see appendix F: F5 and F7). Unfortunately, there were too few subjects in the stroke cohort to permit separate analysis.

9.4.3. The effect of age and gender

The potential for change in thoracic angle as a result of therapeutic intervention fell off markedly in subjects who were aged over 70 years. This age effect, although present for all of the measurements of thoracic extension, was significant for deep breathing, upright standing and walking, with older subjects showing little or no apparent improvement in thoracic angle compared to the younger subjects. The literature indicates that thoracic kyphosis angle increases [20, 29, 31] and range decreases [3, 7, 44] as a function of age. This loss of mobility may be the effect of age-related increased thoracic cage stiffness with resultant alteration in costovertebral kinematics as was discussed in 2.4.2. However, this is the first study to have identified a loss of therapeutic response associated with increasing age. This gives rise to an important public health message, i.e. that people under the age of 60 should be encouraged to take measures to improve their spinal posture before the potential for improvement is lost. The effect of specific interventions designed to maintain costovertebral mobility on kyphosis in older people is a worthy subject for future investigation.

9.4.4. Comparisons between the static and dynamic (6hr) measurements

In this study the FEG was used to measure the thoracic spine because it was capable of capturing dynamic data over the course of a normal day (6hr FEG). These dynamic data were therefore arguably more representative of functional change in kyphotic angle as opposed to the static measurements which are usually captured in studies of this type. The data showed that the specific static FEG measurements which correlated most with the mean 6hr FEG (dynamic) measurement were relaxed standing and walking (Table 9.14). Upright standing, which represented 'best' standing posture was less well correlated. The minimum 6hr angle was smaller than the static 'reaching for the ceiling' measurement by 5° to 6° indicating that the minimum measurement probably occurred in the context of dependent or 'passive' posturing such as sitting or lying down as well as during actively-achieved postures. Certainly it was observed that if the subjects took a nap on a bed, they tended to have a period of extreme flexion followed by extreme extension, or *vice versa*. Similarly, some sitting periods were marked by smaller thoracic angles indicating a more extended spine, presumably because the subject reclined in an armchair.

The 6hr FEG recorded greater ranges of thoracic motion than could be inferred from the static measurements. The range of thoracic motion inferred from differences between the measurements for toe touching and reaching for the ceiling was 15° ± 0.9° whereas the 6hr range was greater than 27° ± 0.7°. As was previously mentioned the 6hr measurements took into account both active and passive postures and so arguably represented a more accurate picture of the thoracic posture assumed during the day. Therefore the measurement of active range only misrepresents the true range of movement of the spine.

The discrepancy between the 6hr range and the static range is interesting. There is an implication that the erector spinae are too weak to be able to extend the thoracic spine fully against gravity. Weakness of the erector spinae resulting in an inability to remain upright is called camptocormia (chapter 2, 2.5.1.5). The data suggest that unrecognised, or subclinical, camptocormia may be common and so may have been present in this group of subjects. One of the subjects, an elderly female who was randomised to the CON group, illustrates this well. Her angles on baseline testing were much lower than they were at 12 weeks. On further inspection it was clear that in sitting her back was much more extended than when walking revealing a reduced ability to maintain full extension in standing. The interesting possibility that sub-clinical camptocormia involving the thoracic erector spinae may have been responsible for the disparity in the static and dynamic range measurements present in a number of the subjects cannot be ruled out since the subjects were aged between 40 and 85 and the incidence has been reported to increase with age [631].

9.4.5. Movement frequency

This is the first study to have measured movement frequency in the thoracic spine in humans. This study revealed that during the course of 6 hrs of a normal day the subjects moved their thoracic spine more than 5° a mean of just 5 times in the sagittal plane, and 10 times in the coronal plane. Previous modelling of spinal movement and disc diffusion mechanics has determined that dynamic disc compression has a dramatic effect on oxygen and lactate concentrations in the intervertebral discs (2.5.1.3). In a study of the effects of static versus dynamic disc compression, Huang and Gu (2008) found that the frequency at which the disc was compressed had a dramatic effect on the change in concentrations of both oxygen and lactate with a reduction of approximately 50% when the frequency was reduced from 0.1Hz to 0.01Hz [273]. Our data indicate that, in the thoracic spine, the frequency of movement in this adult population with a mean age of 66 years was closer to 0.01 Hz than 0.1 Hz in both sagittal and coronal planes. This low frequency of movement may be insufficient for adequate disc nutrition.

Increased kyphosis was significantly associated with decreased sagittal plane movement frequency and increased age was significantly associated with decreased coronal plane movement frequency. It is not possible to determine whether the coronal plane movement was principally rotation or side flexion but it is assumed that, since they are coupled movements (2.4.2), both were represented.

The implication of these findings is that coronal plane movement is reduced as a function of increasing age while reduction of sagittal plane movement frequency is not necessarily a function of age but of thoracic angle. Therefore, if thoracic extension is maintained, movement frequency, and therefore disc nutrition, may not be as compromised during later life. Thoracic kyphosis has been related to degenerative disc disease [21]. It is assumed that degenerative disc disease is, therefore, a primary cause of age-related kyphosis (2.5.1.3). However, it is also possible that degenerative disc disease is secondary to the reduced movement frequency associated with a pre-existing kyphosis. Further longitudinal studies are required to investigate this relationship.

Another interesting finding was that the group who received back extension exercises demonstrated a trend towards decreased coronal movement frequency consistent with a stabilising effect on the trunk. As discussed above, if the strengthening exercise resulted in an increase in abdominal effort such that thoracic extension was inhibited then the net effect may have been a more kyphosed and less mobile spine. If this effect then leads to a secondary decrease in disc nutrition, efforts to improve function with strengthening may actually be deleterious. Further investigation into the effects of various forms of back strengthening with different loads on thoracic movement frequency would be of significant interest.

The frequency data reported in this study could be useful in informing and developing the complex mechanobiological models of the intervertebral disc developed by researchers such as Huang and Gu [273]. It has been suggested that this area of investigation has the greatest future potential in spinal research because spinal degeneration and healing are both mediated by the activity of cells which are acutely sensitive to their local mechanical environment [632]. Information about frequency of inter-segmental movement is also important to any clinician who is responsible for measuring and advising clients about optimising their movement performance.

9.4.6. Back extensor strength and thoracic kyphosis

In this study the relationship between back extensor strength (BES) and thoracic angle was weak. Of all the standing thoracic angles, only relaxed standing FEG angle was significantly correlated with normalised myometry ($r = 0.24$, $p = 0.04$). The positive relationship, however, indicates that the subjects with increased strength had larger thoracic angles. This does not accord with previous findings which reported a significant negative correlation between back extensor strength (measured in prone lying) and thoracic angle ($r = -0.30$, $p = 0.019$) [12].

It has been suggested elsewhere that back extension strengthening exercises can result in a reduced thoracic kyphosis [221]. However, the results of this study do not support this suggestion since there were no significant correlations detected between change in BES and change in thoracic angle. Other studies which have been cited as support of the efficacy of extension exercises in reducing thoracic kyphosis differ from this study in that their subjects were osteoporotic women. There are also significant flaws in the methodology of these previously published studies. For example, Sinaki and Mikkelson in 1984 compared the effects of flexion and extension exercises on progression of bony deformity in women with radiologically-confirmed osteoporosis [580]. They found that a higher percentage of subjects who performed flexion exercises developed further bony deformity on X-ray during the following 1.4 to 2 years. The results of this study were interesting and very influential. However, the study was neither randomised nor controlled: exercises were allocated according to the choice of the treating physician and the treatment groups were unbalanced. The ‘no exercise’ group was given postural education and some subjects were also instructed to do abdominal exercises. As a result it is not possible to determine whether back strengthening exercises reduced the incidence of further bony deformity or whether flexion exercises increased it. In a subsequent prospective study, Itoi and Sinaki (1994) evaluated the effect of a 24 month programme of resisted back-strengthening exercises in prone lying on thoracic angle in 60 healthy, oestrogen-deficient, women [10]. They found no difference in thoracic angle between the exercise and control groups after this prolonged period of exercise. In a secondary analysis, the authors subdivided their cohort into two groups based on how much their BES increased over the 2 years. The groups were not equal, with 27 subjects in the stronger group (increase $\geq$ 21.1 kg) and 33 in the weaker group (increase in BES < 21.1 kg). They then divided the groups into people with more or less kyphosis and found that, amongst the subjects with substantial kyphosis (i.e. > 34.1°), the subjects with a significant increase in back extensor strength had a significant decrease in thoracic kyphosis (-2.8° +/- 4.2°; $p = 0.041$). Although a relationship between strength and kyphotic angle was detected, prone back extension exercises were not shown to have any significant effect. Their conclusion that "increasing the back extensor strength in healthy oestrogen-deficient women helps decrease thoracic kyphosis" [10] is, therefore, misleading.

9.4.7. Posture classification and the thoracic spine

In this study the most common posture type was kyphosis/lordosis (K/L) (49%), followed by sway-back (34%), flat-back (10%) and normal (7%). This differs from the results reported by Smith and O'Sullivan (2008) for adolescents in that their largest group was normal (neutral - 30.2%) followed by sway-back (25.6%), flat-back (22.5%) and K/L (hyper-lordotic 21.8%) [446]. As was the case in the current study, Smith and O'Sullivan found that flat-back posture, and to a lesser extent sway-back posture, were more prevalent in males. In this study, the males who were classified as 'normal' did not have the straightest thoracic spines. They did, however, have the largest 6hr range of movement. The females were different. Those who were classified as normal did have the straightest thoracic spines but they recorded a smaller 6hr range than the females who were classified as flat-back. Whether these differences would be found in a larger cohort is uncertain but studies of differences between male and female posture in sitting have found that males tend to sit in a slumped position with lumbar flexion whereas females tend to be more erect with lumbar extension [83, 583]. The difference in sitting posture may therefore have affected the range measurements seen in our cohort with the males demonstrating greater thoracic flexion ranges. One subject commented that the improvement she noticed most as a result of doing the strengthening exercises was not that she was more erect but that she could more easily tie her shoelaces.

Flexion exercises are not encouraged in the elderly population because there is some evidence that they can lead to vertebral collapse [580]. That study, however, was neither randomised nor controlled and the use of both extension and flexion exercises may need to be reviewed with a view to investigating the risks of both.

The number of subjects was too small to draw any firm conclusions, but it is interesting to note that the prevalence of the K/L posture type was increased in this older cohort compared to the adolescent cohort studied by Smith and O'Sullivan (2008). Malicka et al. (2010) found that increased BES was associated with increased lumbar lordosis relative to thoracic kyphosis [633]. They also found that when the thoracic kyphosis was much greater than lumbar lordosis such as in the sway-back posture type, the BES was reduced. The small number of subjects in the normal and flat-back posture types precludes a useful analysis of the treatment effects by posture type in this study but this information would potentially be very useful to clinicians when making decisions about treatment choices. With this in mind, further investigation is warranted.

9.4.8. Limitations of the study

The main limitation of this study was that the number of subjects was relatively small, especially in the stroke cohort. A power analysis was not performed prior to the commencement of this trial because of an absence of data on which to base such an analysis. The aim was to recruit 80 subjects in each of the normal and stroke cohorts in order to randomise 20 to each of the intervention groups. Over the three years that the trial was conducted a total of 61 normal subjects and 14 stroke subjects were randomised. It is possible that the inclusion of additional subjects may have resulted in more definitive results but this is difficult to judge. Greendale et al. (2009) concluded that for a power of 80%, they required a sample of 120 for a controlled single intervention study of yoga [9]. This allowed for a 20% attrition rate and a minimum detectable difference in Debrunner kyphosis angle of 7.82°. Their results in terms of kyphotic angle change, however, were comparable to those reported in this study indicating that the larger cohort did not yield radically different results. In terms of significant findings, the value of the current study may have been limited but trends have been observed and the findings have pointed to a number of interesting areas for further investigation. There were twice as many females than males in the normal group which may limit the generalisability of the results.

Recruitment to the study may have been adversely affected by the demands of the interventions in terms of regularly attending a gym. The normal subjects were recruited from the community and the strategies for recruitment were reasonably effective. Many of the potential subjects who applied for information about the trial were put off by the requirement to be available to attend the gym three times a week. This was particularly the case for people with families who were working. For some people it was the time and resources required to travel to and from a gym which presented the barrier even though the time spent there was considered very manageable at 15 - 20 minutes. The stroke subjects were much more difficult to recruit than anticipated. The recruitment strategy involved appealing to potential subjects via radio, community posters, talks to community stroke groups and letters of invitation from five neurologists. Many of those who made contact were not sufficiently disabled to meet our inclusion criteria. It is possible that subjects who could have met our inclusion criteria but did not apply felt that the effort of potentially having to attend the gym on three days a week was too difficult to manage. One lady who was keen, and would have been eligible, could not manage to get to the gym if required because her elderly husband was no longer able to drive. The people who did participate either owned a car and were independently mobile around the community or had a partner who was enthusiastic about them being more physically active. The design of this study would have been enhanced if we could have had better access to potential subjects and been able to offer either transport or a home-based intervention for some people. It should, however, be stated that for many of the normal and stroke subjects, the opportunity to attend a gym was a draw card and the compliance was high (85% to 89% attendance).

The definition of the intervention 'postural re-education' was loose and open to interpretation by the treating physiotherapists. The physiotherapists were at liberty to teach stretching and strengthening and to use mobilisation if they deemed it necessary. Better delineation between the intervention strategies could potentially have been achieved with a programme which involved teaching of postural principles only, but this approach would not reflect current practice. The intervention used allowed the physiotherapists to draw upon their knowledge and experience to devise what they judged to be the best programme for the individual subject, thereby better approximating current practice.

A further limitation is that it is difficult to compare the results with other studies in which prone extension exercises rather than the sitting extension exercises were used. Prone extension has been widely used in other studies and is commonly used clinically. A future study could compare the effects of a 12 week strengthening programme in a sitting position against a programme in a prone lying position to determine which was more effective at reducing the thoracic angle. In this study sitting was used because it is more accessible to a broader group of participants, including those with stroke; and because it was found to be more effective for the thoracic spine (see chapter 7).

Another limitation in comparing this study to others is that the section of the spine measured by the FEG was not the same as that measured in other studies. This was the first study to use the FEG to collect thoracic angle data over the course of a normal day. Because the FEG was limited to 24 cm the levels measured were predominantly between T3 and T10 or T11. Other intervention studies have used a kyphometer or the flexicurve to measure the angle between T1 and T12. A longer FEG would have enabled the thoracic angle between T1 and T12 to be measured. However, many studies which have used the Cobb angle (considered to be the clinical standard for static measurement) have measured between T4 and T11 or T12 which is similar to that measured by the FEG in this study. As mentioned above, a study which utilized the FEG to measure the whole thoracic spine as well as the upper, middle and lower thoracic regions would provide valuable insights into the effect of treatments in the future.

The toe touching measurement may not have elicited the maximum flexion angle. Toe touching recorded thoracic angles of 7° to 8° less than the maximum 6hr angle. Although the maximum 6hr angle may also have been the result of a passive posturing, in retrospect toe touching may not have been a good test of maximum thoracic angle. Many subjects actually decreased their thoracic angle compared to baseline when touching their toes which was not expected. It is suspected that an increase in hamstring muscle extensibility enabled them to reach to their toes with more hip flexion and less thoracic flexion.

The threshold for the movement frequency data was arbitrarily chosen. The threshold was measured as a change in rotation greater than 5° This threshold was used because 5° is commonly believed to be the minimum clinically significant difference required for Cobb angle measurements [332]. However, the threshold could equally be set at 3° because this is within the accuracy of the FEG [408]. A future study could compare the frequencies measured using a threshold of 3° with those measured using a threshold of 5°.

The stroke cohort was disappointingly small. In retrospect, It may have been prudent to have included people with modified Rankin scores of 1 or 2 bearing in mind that they may have

9.4.9. Conclusions

The main aim of this study was to assess the relative effects of strengthening and postural re-education on thoracic kyphosis. Although there were few statistically significant differences', strengthening, either combined with postural re-education, or alone, was shown to be marginally more effective than postural re-education alone. Comparison between the measurements of the whole spine and those of the middle section seem to indicate that the upper thoracic spine may be more amenable to change than the middle section including the apex. The data also indicate that the potential for improvement is minimal in the subjects who were aged over 70 years. Thoracic spine movement frequency was very low in the in both sagittal and coronal planes and increased kyphosis was associated with a decrease in sagittal movement frequency. The stroke subjects were shown to be slightly more kyphosed at baseline than the normal subjects but there was no difference in their response to intervention. Contrary to the conclusions reported in the literature, increased BES had no significant effect on kyphotic angle and there was only a very minimal association between the two at baseline. The effect of strengthening on kyphotic angle, however, may have been attenuated by the application of too much load. Further investigation would potentially clarify this issue. Also, future studies of interventions for kyphosis would benefit from differentiating between the upper, middle and lower thoracic spine. Finally, it is possible that the measurement of thoracic spine angle may actually be a por way of measuring the outcome of any programme which aims to improve the wellbeing of older people with hyperkyphosis. In these people disability indices and quality of life measures may be more sensitive markers.

Chapter 10.

Concluding Remarks

http://theneurosurgeon.com/conditions/osteoporosis.htm

10.1. Introduction

The broad aim of this thesis was to investigate some of the underlying assumptions which underpin the conservative treatment of age-related hyperkyphosis of the thoracic spine. More specifically, the main aim was to examine the relative efficacy of the most commonly used conservative treatment strategies in reducing age-related hyperkyphosis. The thesis, therefore, consists of a number of studies which were designed to inform the design and execution of the RCT comparing postural re-education and strengthening in normal subjects and those with stroke. The findings of each chapter all address the broad aim of challenging underlying assumptions made in day-to-day clinical practice. This thesis, therefore, contributes to the growing body of literature relating to the treatment of age-related hyperkyphosis.

The specific hypotheses are stated in section 1.2 and a thorough discussion of the findings of each of the studies conducted for this thesis is contained within each of the previous chapters. The following remarks aim to bring together the most interesting ideas which have emerged from the thesis as a whole rather than to repeat these discussions.

10.2. Synthesis of the Findings and future directions

The following remarks are made in order of their position within the thesis and not in order of importance.

10.2.1. The use of the FEG

This was the first time that the FEG has been thoroughly validated and used in a clinical thoracic spine study. The FEG was used because it was capable of measuring the kyphotic angle throughout the course of the whole day as distinct from the static measurements which have been made in previous studies. The mean FEG angle was found to be most closely correlated with the relaxed standing and walking FEG angles. This demonstrated that upright (fully extended) standing angle was not the best measure of functional back posture and that, of the static measurements, relaxed standing and walking angles are probably more meaningful.

The 6hr FEG measurements of range were larger than the range imputed from the static measurements. The most likely reason for the disparity is that the 6hr measurements included passive as well as active ranges. This finding highlights the need to identify what the intervention being measured is seeking to achieve. If an increase in active range only is sought, then the 6 hr measurement may not be required and the measurement of full active extension is essential. However, functional range includes passive range and should therefore arguably be assessed as an outcome. Further, an increase in the ratio between passive and active range might indicate erector spinae weakness and potential camptocormia needing further investigation.

The FEG used in the studies presented in this thesis was only 24 cm long and therefore did not measure the thoracic spine from T1 to T12. This was not considered to be a problem since it was the apex of the spine which was considered to be the target measurement area. However, as discussed in chapter 9, there were potentially larger changes available in the upper thoracic spine than in the middle section. A FEG which measures the spine in sections and also as a whole would be a useful tool in this area of research.

10.2.2. Current physiotherapy practice

The survey of Australian physiotherapists indicated that numerous strategies are employed to treat hyperkyphosis but that the major three were postural re-education, strengthening and stretching. Stretching was not directly addressed in this research but future research should evaluate the role of stretching possibly in a design such as this one.

The survey also disclosed the fact that Australian physiotherapists principally use visual inspection only to evaluate the extent to which their intervention has influenced the spinal curvature. Visual inspection, however, is not a reliable assessment tool [337, 345, 544] and evaluation of treatment efficacy is unlikely to be objective using this technique. Other validated assessment tools such as the FEG, the flexicurve, the kyphometer or inclinometers should be better promoted in order that they become more accepted by clinicians. In this way clinical judgements will be more objective and experimental findings can be better assessed in the field.

Finally, the feedback from the survey respondents indicated that many physiotherapists felt underinformed about the thoracic spine and the effective treatment of hyperkyphosis in particular. It is therefore important that thoracic spine research is clinically relevant, accessible, reported and included in undergraduate courses and professional development programmes.

10.2.3. sEMG of the erector spinae

The validity of the T3 and L4 sEMG sites for measuring the activity of the thoracic and lumbar (respectively) erector spinae muscles was examined using real time ultrasound. It was found that the T3 site was completely obscured by the trapezius muscle during extension activity *in vivo.* In addition it was concluded that sEMG electrodes should be positioned just 2 cm adjacent to L4 when recording the lumbae erector spinae in order to avoid crosstalk from latissimus dorsi. This finding led to the need to use a combination of sEMG and force measurements to calculate the contributions of the thoracic versus the lumbar erector spinae to extension in prone and sitting. However, the force measurements were used in lieu of actual EMG data. It was suggested by one of the reviewers of the paper published from the ultrasound study (chapter 6) that the measurement of the thoracic erector spinae could potentially be achieved by applying multiple sEMG sensors and subtracting potential crosstalk signals. However, these techniques have not been documented or validated for the thoracic erector spinae muscles. A further study is therefore required to validate a reliable method of measuring thoracic erector spinae activity.

10.2.4. The back extension exercise

The studies presented in chapters 6 and 7 which compared extension in sitting to extension in prone lying revealed that thoracic extension and the contribution of the thoracic erector spinae (TES) were comparatively reduced in the prone lying extension exercises while the abdominal muscle contribution was increased. It is suggested that the explanation for this pattern of activity may be related to the way in which the trunk executes extension when it is required to extend against significant resistance. It is hypothesized that, because the trunk is heavy, the TES are unable to efficiently raise the trunk from prone. This is because they are at a mechanical disadvantage due to their very short lever arms. In order to overcome this problem it is proposed that the flexor muscles (abdominal and latissimus dorsi muscles) are recruited to stabilise the thoracic spine into an arch (like the string of a bow), thereby allowing the stronger lumbar spine erector spinae, assisted by the gluteal and hamstring muscles via the thoraco-lumbar fascia, to lever the thorax into extension. An alternative hypothesis may be that the abdominal muscles are recruited to stabilise the pelvis in order that the thorax can be lifted from a point of stability. However this does not explain the relative reduction in TES contribution.

The resistance which the thoracic extensors must overcome during prone lying extension exercises is not uniform. Because the weight of the trunk differs between individuals, the resistance is greater in heavier individuals than it is in lighter people. However, in sitting the effect of gravity is relatively neutral (although weight may actually be an advantage in terms of exerting force in the direction of extension during testing). In the sitting position, unresisted extension with scapulae retraction was shown to produce the most thoracic extension range. However, in the RCT this extension exercise was performed with resistance. The subjects were trained to extend their thoracic spines against a load which was designed to be sustained at 60% of 1RM throughout the course of their programme. However, the effectiveness of this strategy was limited.

There was no significant reduction in kyphotic angle despite an improvement in physical function tests and strength. One explanation may be that 60% of 1RM was too high a resistance dose. The suggestion by one of the subjects that increasing the resistance too much resulted in them feeling shorter was a good clue that this might be the case and is consistent with previous reports of increased kyphosis in trained athletes compared to their sedentary peers [210].

The RCT was not designed to identify the ideal training regimen for the TES so further investigation into the effects of load and intensity on the relative activity of the muscles of the trunk is required. This would identify whether there is an intensity and load at which extension exercises most effectively improve thoracic extension strength and posture.

10.2.5. Scapular retraction and posture

Scapular retraction had a marked effect on both the force of extension in sitting and the degree of thoracic extension. This was probably the result of the action of the middle fibres of trapezius. Contraction of this muscle has been reported to unify the shoulder girdle into a stable yoke [155]. By ‘fixing’ the spine to a stiffened shoulder girdle the flexible rod of the spine is theoretically stiffened by a factor of sixteen [183] thereby enabling it to produce a more powerful extension moment. Another possible explanation may be that the contraction of the superficial trapezius increased the effect of the thoracic erector spinae by ‘hydraulic amplification’. By compressing the extensor compartment and restricting the radial expansion of the erector spinae the increased hydrostatic pressure within the compartment may have allowed the erector spinae to function hydraulically thereby adding to their effectiveness [208]. Physiotherapists commonly instruct their patients to retract and depress their scapulae to achieve good posture and many of the subjects in this study remarked that this strategy was very effective. This effectiveness of this strategy could be explained by either of the theories presented above.

Biomechanical modelling of the theoretical explanations outlined above (i.e. the creation of a stable yoke by trapezius or the theory of hydraulic amplification) may further explain why scapular retraction results in better thoracic extension. In this way more effective methods of improving postural alignment and control may be achieved.

10.2.6. The effectiveness of the interventions

The two interventions examined in the RCT had no significant effect on the kyphotic angle. However, the response to strengthening was greater when the upper thoracic segments were included in the measurement implying that the strengthening intervention had the most effect on the upper thoracic spine (T1 to T3). These findings are important since many of the theoretical benefits of reducing the kyphotic angle (e.g. decreasing the anterior compression forces) are predicated on the assumption that the angle is reduced at the apex. Because other studies have reported a reduction in kyphosis measured between T1-T12 it has been assumed that the change represents an alteration in the entire curve including the apex. The result of this study suggests otherwise. Future studies should differentiate between changes at the different spinal levels in order to ascertain the actual effects of their interventions.

The strengthening intervention resulted in significant improvements in BES. However, the fact that kyphosis didn't decrease in spite of an increase in BES suggests that the relationship between back extensor strength and kyphotic angle is not as clear as has been previously suggested. As suggested in 10.2.4, further investigation of the effect of different loads on the efficacy of extension strengthening exercises for reducing kyphotic angle is required to clarify this relationship.

The subjective responses indicated that the subjects enjoyed the strengthening intervention more than the postural re-education intervention alone, and that they were more positive that their posture had changed. The strengthening intervention took place in a gym and most of the subjects enjoyed that environment, at least in the short term. On balance, receiving both interventions seemed to be most advantageous, but strengthening was the more influential of the two interventions.

10.2.7. The frequency of spinal movement

To our knowledge the measurement of frequency of thoracic spine movement has not been reported before and yet movement frequency may be one of the keys to maintaining good disc health. It was a surprise to discover that the movement frequency was so low, much lower than the values used to model the intervertebral disc in the published finite element modelling studies [273].

The fact that movement frequency reduces with increased kyphosis begs the question: is it the increased kyphosis which decreases the movement frequency or decreased frequency which contributes to disc disease which eventually leads to hyperkyphosis? If it is the latter then strategies to maintain movement frequency may emerge as a potent method of reducing the incidence of age-related hyperkyphosis.

Further research looking at normal values of movement frequency in a larger population of both children and adults of varying ages may provide more insight into the natural history of movement frequency decline with age, if indeed it does exist.

10.3. Conclusions

This thesis has contributed to the literature in a number of ways. It has:

- Validated the FEG for use in studies of the thoracic spine,
- Found that Australian Physiotherapists primarily assess kyphosis visually and primarily treat with postural re-education, stretching and strengthening,
- Determined that seated extension exercises with scapula retraction recruit the TES better than prone lying extension exercises,
- Found that direct sEMG recording of the thoracic erector spinae at T3 during extension is not possible because of the dynamic anatomy of the trapezius muscle,
- Validated a simple method of seated myometry,
- Shown for the first time that thoracic movement frequency in adults is lower than the level which has been reported to be necessary for adequate disc nutrition,
- Found that a 12 week programme of progressive resisted strengthening and postural re-education had no significant effect on the angle of thoracic

kyphosis in non-osteoporotic adults even though strength and physical function scores improved with strengthening.

The idea for this research came from the clinic. It is therefore apporopriate to briefly discuss what guidance physiotherapists might take from this research. First, although the FEG is possibly a little time consuming to be a useful day-to-day clinical tool, physiotherapists who are interested in detailed dynamic evaluation may be interested in the methods that have been developed. The survey results suggest that a more rigorous approach to measurement might yield more realistic results in terms of the effect of treatment for this problem and perhaps others. The survey also highlighted the high degree of uncertainty that most physiotherapists have in deciding how best to manage hyper-kyphosis. Physiotherapists can be confident that seated extension exercises with scapulae retraction are an effective method of recruiting the thoracic erector spinae but the use of progressively incremented resistance is probably essential for measurable increases in strength. Finally, it seems from this study and others, that reducing the angle of kyphosis is a difficult thing to do and that, although strengthening may play a part, it is not the whole answer and 12 weeks is not a sufficient amount of time to achieve a measurable change.

These results have generated even more research questions but they have also provided a few small pieces of a puzzle which continues to surprise and perplex researchers and clinicians alike.

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APPENDICES

Appendix A – The survey

A1 The survey comments

Forty eight of the respondents generously offered additional comments. The majority fell into 7 main areas.

1. “Thoracic kyphosis is not actually the reason that patients present to a physiotherapist. Patients present with cervical, shoulder or lumbar pain, headache and/or thoracic pain. The treatment of kyphosis is therefore used to reduce pain in the presenting area rather than because it needs treating in its own right.” (22/48)
2. “The management of thoracic kyphosis is an area that physiotherapists feel unsure about. There is a feeling that more research would be very helpful. Addressing thoracic kyphosis now is very timely in view of the increased computer use in the community, particularly in the young.” (12/48)
3. “The posture of the thoracic spine is a key to the successful management of all spinal problems and is often overlooked.” (5/48)
4. “Thoracic kyphosis encountered in older patients (or over 40s) is related to osteoporosis (crush fractures) and the postural changes are difficult to influence with physiotherapy modalities. The focus is more on preventing falls.” (5/48)
5. “Balance and exercise classes such as Tai Chi are the most effective modality for postural problems in the elderly.” (4/48).
6. “Thoracic kyphosis is primarily the result of increased cervical lordosis.” (3/48).
7. “Mobilisations are useful for pain relief in the thoracic region.” (3/48).

A2 The eight categories into which each of the individual treatment modalities selected by the respondents were placed.

Category	Individual treatment modality	Number of respondents
Postural Re-education	Postural re-education	164
	Thoracic ext - general	60
	Taping	41
	Ergonomics	28
	Neck retraction	20
	Alexander Technique	1
	Scapula retraction/ repositioning	1
Stretching	General postural stretches/ROM	70
	Thoracic ext - local/towel or roll device	42
	Pectoral stretch	23
	Thoracic rotation	17
	Hip/lower limb stretches	3
	Muscle Energy Technique	2
	Neural tension release	1
Strengthening	General postural strengthening	73
	Scapula stabilisation	36
	Core stability	27
	Resisted scapula retraction	17
	Resisted thoracic ext	16
	Hydrotherapy	12
	Shoulder exercises	11
	Yoga	2
	Resisted neck retraction	1
Joint Mobilization	Joint mobilisation/manipulation	108
Soft Tissue Mobilization	Soft tissue mobs	29
Bracing	Back brace	11
	Specialist bra	1
Other	Breathing exercises	7
	Electrotherapy	10
	Acupuncture	1
	Regular exercise advice	10
	Balance/coordination exercises	1
No response	No response	10

Note. The numbers indicate the number of respondents who reported using the modality.

Appendix B – The RCT Information Pack

B1. Cover letter for information pack sent to potential RCT participants

ANU
THE AUSTRALIAN NATIONAL UNIVERSITY

ANU COLLEGE OF MEDICINE & HEALTH SCIENCES

Trauma and Orthopaedic Research Unit
Level 1, Building 6
The Canberra Hospital
6244 4133
0439 334 782
Diana.Perriman@anu.edu.au

Dear participant,

Re: Kyphosis Posture Study Participation

Thank you very much for considering taking part in our study. Contained within this pack is:-

1. An information sheet about the study
2. A consent form – **to be signed at the assessment** with a witness.
3. A baseline data collection form with three questionnaires attached.

If after reading the study information sheet and consent form you are happy to participate, could you look at the data collection form and questionnaires?

I hope all this paperwork doesn't seem too daunting. I felt that you would prefer to answer a lot of the questions in the comfort of your own home rather than extending the amount of time spent at the first assessment. If you have trouble with any of the questions please feel free to leave them and we will review them when I see you.

In the next week I will contact you to ask if you are willing to participate. If you are, I will make an appointment which is mutually convenient.

I have printed a map with closest parking areas on the back of this letter and my telephone numbers are above in case you are finding it difficult to locate me. I will put some signs up inside the building to guide you.

The assessment will take approximately 1 hour and will involve attaching a device to your back with a recording box at your waist which you will wear for the day. I will remove it after about 6 hours either here or at your home, whichever suits you best. The removal takes only minutes.

Once again, thank you very much for your help.

I look forward to seeing you on the assessment day.

Best wishes,

Diana Perriman
(Physiotherapist and Researcher)

B2. Information sheet included in pack sent to potential RCT participants

THE CANBERRA HOSPITAL
YAMBA DRIVE, GARRAN ACT 2605
PO BOX 11, WODEN ACT 2606
telephone: (02) 6244 3858
facsimile: (02)6205 2157

PARTICIPANT INFORMATION SHEET

Posture Study
A study being carried out at The Canberra Hospital, Canberra.

Principal investigators:

- Diana Perriman, PhD candidate
- Associate Professor CJ Lueck, Dept Neurology, The Canberra Hospital.
- Associate Professor Paul Smith, Dept Orthopaedics, The Canberra Hospital.
- Dr Andrew Hughes, Department of Neurology, The Canberra Hospital,
- Dr Jennie Scarvell, Dept of Surgery, TCH.

Thank you for your interest. We are asking you to participate in a study that is looking at the development of increased curvature of the spine (kyphosis) and its effect on function with normal ageing and in stroke.

As with all studies of this kind, your participation is entirely voluntary. You are free to decline to take part either from the start or at any point during the study.

Outline of the study
If you do decide to take part in the study, we will ask you to have some baseline measures done before being randomised to one of the **four groups**: strengthening exercise, postural exercise, strengthening <u>and</u> postural exercise or no exercise. After twelve weeks you will be measured again just as you were at baseline.

What are the baseline measurements?
The baseline measurements will involve asking you some questions about your life, some simple walking, balance and chest expansion tests as well as some specific measurements of your spine. The main spinal measurement will involve fitting a 'flexible electrogoniometer' (FEG for short) to your back (see figure 1).

What is a flexible electrogoniometer (FEG)?
The FEG is made out of plastic and metal and is entirely harmless. It sends a signal via a cable to a recording box (the datalogger) which we would ask you to wear in a pouch attached to a belt around your waist. The datalogger weighs approximately 655grams (just over 1lb) and the electrogoniometer weighs under 100 grams.

How is the FEG applied?
We will need to ask you to remove your upper garments (leaving your bra on if you are a woman) so that we can tape the FEG to the skin overlying your spine (we will use a special tape which is gentle on the skin and does not cause an allergic reaction). Applying the FEG should take just a few minutes after which we will ask you to wear the device

during your normal day-to-day activities for 6 to 8 hours. During this time we would ask you to record what you are doing on a sheet that we will give you. At the end of the day the device will be removed by the researcher, preferably back at the Canberra Hospital but, if necessary, in your home.

Figure 1: Flexible electrogoniometer attached to the upper thoracic spine with datalog on the right

What exercise am I expected to do?

This depends on which group you are randomised to and cannot be known prior to the study. The three groups are as follows:-

- **The strengthening exercise group**
  In the strengthening group you will be asked to attend the Southern Cross Gym in Phillip or ANU gym <u>no more than</u> three times a week to do a very simple back exercise using an exercise machine. After the initial instruction you will see the researcher two more times in order to check your exercise but she will be available at most times should you have any difficulty. There will be no cost for gym attendance and special clothing is not necessary.
- **The postural exercise group**
  In the postural exercise group you will have specific instruction by a physiotherapist up to three times over the 12 week period. This will involve strategies for improving and making you more aware of your posture.
- **The strengthening and postural exercise group**
  This group will be asked to attend the gym and have a physiotherapist advise them on their posture.
- **The no exercise group**
  In the no exercise group you will not do anything different to what you usually do. You will merely be measured at baseline and then again after 12 weeks.

We will need to ask you some basic questions about yourself. We will need to obtain your contact details (address and telephone numbers) in order to contact you to arrange for you to come up for the measurements. We will need to know your date of birth because one of the major questions we are asking relates to the effect of age on the development of spinal curvature. If you are taking any medication for any medical condition, we will need to know because many medications can interfere with limb movements during walking. We will also want to know about how well you cope with activities of daily living.

Please be assured that your personal details will be held securely in a locked filing cabinet at the hospital, and on our study computer. They will be used only for the purposes of contacting you. If we may, we would like to keep your information on this computer in case we are performing other studies in the future in which you might be prepared to participate, and for the purposes of obtaining longer term follow up information. We will not divulge this information to anyone else. Any data or clinical details we record from you will be anonymous from the start – your data will be given a subject number, and all clinical information and FEG recordings will be tied to that number, not to your name. This number is all that anyone looking at the data in the future will be able to access.

The ACT Health Human Research Ethics Committee as well as the ANU ethics committee has approved this study.

Thank you very much for reading this. If you have any questions, please feel free to ask at any time. As above, even if you give your consent to begin the experiment you are free to withdraw your consent at any time, and we will immediately discontinue the experiment. If you are undergoing medical treatment of any sort, your treatment will be entirely unaffected whether or not you participate in this study. Specifically, withdrawal of consent will not jeopardise your medical treatment in any way.

Diana Perriman,
Trauma and Orthopaedic Research Unit,
6244 3858
Diana.Perriman@anu.edu.au

B3. Consent form included in pack sent to potential RCT participants

THE CANBERRA HOSPITAL
YAMBA DRIVE, GARRAN ACT 2605
PO BOX 11, WODEN ACT 2606
telephone: **(02)6244 3858**
facsimile: (02) 6205 2157

Consent Form to Participate in a Research Project

(Version 6, 16th July 2007)

I, ________________________________
(name of participant)

of ____________________ ____________________ ____________________
(street) (suburb/town) (state & postcode)

have been asked to consent to participate in a research project entitled:

Electrogoniometric measurement of kyphosis in stroke (Posture Study)

In relation to this project I have read the Patient Information Sheet and have been informed of the following points:

1. Approval has been given by the ACT Health Human Research and ANU Human Research Ethics committees.

2. The aim of the project is to record the movements of the spine during day-to-day activities to determine what causes stooped posture and gait disturbance in normal elderly people, and in patients affected by stroke with a view to trying to prevent or treat these problems.

3. The results obtained from the study will not make any difference to my medical management.

4. The procedure will involve taping a recording device (the flexible electrogoniometer) to my back and wearing a datalogger attached around my waist. The recording device will be attached for a variable length of time, depending on the exact study, but the time will never be longer than 8 hours. I will also have my back shape measured using a flexible ruler and some simple balance, chest expansion and walking tests.

5. After these initial measurements I will be allocated to one of four groups which will involve doing one of three exercise programmes aimed at improving my posture or no exercise. These will continue for 12 weeks after which I will be re-measured in the same way as was described above. If randomised to an exercise group gym attendance of up to 3 times a week may be required. If gym attendance is required there will be no fee.

6. There are no anticipated adverse effects or risks related to this project, though there might be some minimal inconvenience from having to wear the measuring device.

7. My involvement in this project may be terminated if I wish to stop at any point.

8. The researcher for this project is Diana Perriman and she can be contacted on 6244 3602 or 0439 334 782.

9. Should I develop a problem which I suspect may have resulted from my involvement in this project, I am aware that I may also contact Associate Professor Paul Smith on 6124 1672 or Dr Andrew Hughes on (02) 6244 2950.

10. Should I have any problems or queries about the way in which the study was conducted, and I do not feel comfortable contacting the research staff, I am aware that I may contact the ACT Department of Health Ethics Committee Secretary at No 11 Moore St, Canberra City, ACT, 2601 or on phone number (02) 6205 0846 or the Human ethics officer, Human Research Ethics Committee, Australian National University tel (02) 6125 7945 e-mail: Human.Ethics.Officer@anu.edu.au

11. I can refuse to take part in this project or withdraw from it at any time without affecting my medical care.

12. Participation in this project will not result in any extra medical and hospital costs to me. I will not receive any reimbursement for my involvement in this study.

13. I understand that the results of the research will be made accessible and that my involvement and my identity will not be revealed.

14. In giving my consent, I acknowledge that Associate Professor Smith, Dr Andrew Hughes or Diana Perriman may examine my medical records, but only as they relate to this project.

15. No compensation is available for any injury or illness suffered as a result of participation in this study.

After considering all these points, I accept the invitation to participate in this project.

I also state that I have/have not participated in any other research project in the past 3 months. If I have, the details are as follows:

____

Date: ___ **Witness:** ______________________________

(Please print name)

Signature: ______________________ ______________________

(of participant/volunteer) (of witness)

Investigator's Signature: ______________________________

B4. Data collection form included in pack sent to potential RCT participants

POSTURE STUDY DATA COLLECTION FORM

In order to save time could you possibly complete the following details prior to your assessment visit?

Name.. DOB..........................

Male ☐ Female☐

Handedness Left handed ☐ Right handed ☐

How many pillows do you need to sleep? ....

Does anyone in your family have a stoop? Yes ☐ No ☐ Relationship?...

OCCUPATION (if retired previous main occupation - manual, office, outdoors, indoors?)

....

Smoking Never ☐ Current ☐ Former ☐

Have you fallen recently? Yes ☐ No ☐ Number of falls in last 6 months?..........................

Tick if you have any shoulder pain? Right ☐ Left ☐

Tick if you have any limitation of movement in your shoulders? Right ☐ Left ☐

Tick if you have any back pain at this time Lower back ☐ Upper back ☐ Neck ☐

How severe is this back pain? (Mark the line below to indicate how severe)

Lower back No Pain |————————————————| Worst pain

Upper back No Pain |————————————————| Worst pain

Neck No Pain |————————————————| Worst pain

Now complete the following forms attached to this form.

1. Functional Comorbidity Index
2. Physical Activity Score
3. AQoL

B5. The functional comorbidity index form included in pack sent to potential RCT participants

The Functional Comorbidity Index

Name...
Date...
Study No...................................

Do you have any of the following?		Yes	No	Unsure	Comments
1.	Arthritis	☐	☐	☐	
2.	Osteoporosis	☐	☐	☐	
3.	Asthma	☐	☐	☐	
4.	Chronic obstructive pulmonary disease (COPD), acquired respiratory distress syndrome (ARDS, or emphysema)	☐	☐	☐	
5.	Angina	☐	☐	☐	
6.	Congestive heart failure (or heart disease)	☐	☐	☐	
7.	Heart Attack	☐	☐	☐	
8.	Neurological disease (such as multiple sclerosis or Parkinson's)	☐	☐	☐	
9.	Stroke or transient ischaemic attack (TIA)	☐	☐	☐	
10.	Peripheral vascular disease	☐	☐	☐	
11.	Diabetes types I and II	☐	☐	☐	
12.	Upper gastrointestinal disease (ulcer, hernia, reflux)	☐	☐	☐	
13.	Depression	☐	☐	☐	
14.	Anxiety or panic disorders	☐	☐	☐	
15.	Visual impairment (such as cataracts, glaucoma, macular degeneration)	☐	☐	☐	
16.	Hearing impairment (very hard of hearing, even with hearing aids)	☐	☐	☐	
17.	Degenerative disc disease (back disease, spinal stenosis, or sever chronic back pain)	☐	☐	☐	

18. Height ____________ cm or inches
19. Weight ____________ Kg or lbs

<u>FOR OFFICE USE</u>

BMI (>30?) ☐ ☐ ____________
weight (kg) / (height (m))2

TOTAL FCI ____________

Reference – D.L. Groll et al. / Journal of Clinical Epidemiology 58 (2005) 595-602

B6. The Australian self reported generic physical activity questionnaire included in pack sent to potential RCT participants

AUSTRALIAN SELF REPORTED GENERIC PHYSICAL ACTIVITY QUESTIONNAIRE

Name..

Date..

Please complete the first column (you can do the totals if you are interested).

***IN THE LAST WEEK**, what do you estimate was **the total time** that you spent doing the following activities?*	Time spent in minutes	No of METs per minute	Total METS (time X mets)
Walked continuously for at least 10 minutes, for recreation/exercise or to get to or from places?		**3**	
Do any vigorous physical activity which made you breathe harder or puff or pant (eg jogging, cycling, aerobics)?		**7.5**	
Do any other more moderate physical activities that you have not already mentioned (swimming, tennis, etc)?		**4**	
TOTAL			

For your interest only

Metabolic Equivalent (MET) Level

A way of measuring physical activity intensity is by the metabolic equivalent, or MET, level. This unit is used to estimate the amount of oxygen used by the body during physical activity.

1 MET = the energy (oxygen) used by the body as you sit quietly, perhaps while talking on the phone or reading a book.

The harder your body works during the activity, the higher the MET.

FOR OFFICE USE ONLY
Subject Number
Date.................

Diana Perriman
20/5/08

Appendix C – The randomisation letters

C1. Letter to normal subjects randomised to both strengthening and postural re-education (BOTH group)

GROUP A

You have been randomised to Strengthening and Postural Reeducation with a Physiotherapist.

Could I ask you to:-

1. Phone me (Diana) on 6244 4133 0r 0439 334782 in the next few days to arrange a gym session.

2. Phone one of the following physiotherapy practices in the next few days to make an appointment for an assessment. Please explain to the receptionist that you are in the **POSTURE STUDY** when you call.

   - Corinna Physiotherapy Centre, Corinna Chambers, 36 Corinna St, **Woden**. **6282 5010**
   - Timothy Maher and Associates, Suite 3, Level 2, Clinical Services Building, Strickland Crescent, **Deakin** (John James Hospital Site). **62825898.**
   - Timothy Maher and Associates, 2 Luke St, **Kippax**. **62549889**.

The physiotherapist has been asked to assess your posture and review you once or twice over the next 12 weeks. YOU ARE NOT EXPECTED TO PAY A FEE. The invoice will be sent directly to us. The physiotherapy sessions are specifically for assessment and advice about your posture. The physiotherapist will have limited time and has not been contracted to advise on other problems during these 3 sessions.

I will arrange your 12 week assessment when we make your gym appointment.

Many thanks once again for taking part in this study. I hope you will enjoy the next 12 weeks and I will look forward to our gym sessions together.

Best wishes,

Diana Perriman

C2. Letter to normal subjects randomised to postural re-education only (PED group)

GROUP B

You have been randomised to Postural Education with a Physiotherapist

Could I ask you to:-

Phone one of the following physiotherapy practices in the next few days to make an appointment for an assessment. Please explain to the receptionist that you are in the **POSTURE STUDY** when you call.

- Corinna Physiotherapy Centre, Corinna Chambers, 36 Corinna St, **Woden. 6282 5010**
- Timothy Maher and Associates, Suite 3, Level 2, Clinical Services Building, Strickland Crescent, **Deakin** (John James Hospital Site). **62825898.**
- Timothy Maher and Associates, 2 Luke St, **Kippax**. **62549889**

The physiotherapist has been asked to assess your posture and review you once or twice over the next 12 weeks. YOU ARE NOT EXPECTED TO PAY A FEE. The invoice will be sent directly to us. The physiotherapy sessions are specifically for assessment and advice about your posture. The physiotherapist will have limited time and has not been contracted to advise on other problems during these 3 sessions.

One of our team will ring you to arrange the date for your 12 week assessment in the next couple of weeks.

Many thanks once again for taking part in this study. I hope you will enjoy the next 12 weeks and I will look forward to seeing you at your 12 week assessment.

Best wishes,

Diana Perriman

C3. Letter to normal and stroke subjects randomised to strengthening only (STR group)

GROUP C

You have been randomised to Strengthening in the Gym.

Could I ask you to:-

Phone me (Diana) on 6244 4133 0r 0439 334782 in the next few days to arrange a gym session.

Your 12 week assessment will be arranged when we make your gym appointment

Many thanks once again for taking part in this study. I hope you will enjoy the next 12 weeks and I will look forward to our gym sessions together.

.

Best wishes,

Diana Perriman

C4. Letter to normal and stroke subjects randomised to the control group (CON)

GROUP D

You have been randomised to No Intervention

I am not going to ask you to do anything extra at all. I **will** ask you **not** to do anything you don't normally do in terms of training or postural exercise over the next 12 weeks. I will discuss your posture and advise you to the best of my ability after the final assessment if you would like me to do so.

I do hope you are not too disappointed to have been randomised to this group. It is an essential component of the study without which the data would be much less valuable and to be honest, we are not sure that the treatment groups will work yet – that is what this study is trying to find out.

One of our team will ring you to arrange the date for your 12 week assessment in the next couple of weeks.

Many thanks once again for taking part in this study. I hope you will enjoy the next 12 weeks and I will look forward to seeing you at your assessment.

Best wishes,

Diana Perriman

C5. Letter to stroke subjects randomised to both strengthening and postural re-education (BOTH group)

GROUP A

You have been randomised to Strengthening <u>and</u> Postural Reeducation with a Physiotherapist.

Could I ask you to:-

1. Phone me (Diana) on 6244 4133 0r 0439 334782 in the next few days to arrange a gym session.
2. Phone Physiotherapist Christine O'Brien on 6288 0601 to make an appointment. If nobody is home please leave a message with a name and contact phone number and Chris will get back to you.

Christine has been asked to assess your posture and review you twice over the next 12 weeks. YOU ARE NOT EXPECTED TO PAY A FEE. The invoice will be sent directly to us. The physiotherapy sessions are <u>specifically</u> for assessment and advice about your posture. The physiotherapist will have limited time and unfortunately will not have time to advise on other problems during these 3 sessions.

The physiotherapy sessions will take place in the same place as your assessment, here at the hospital. If you require another map to guide you just let me know.

I will arrange your 12 week assessment when we make your gym appointment.

Many thanks once again for taking part in this study. I hope you will enjoy the next 12 weeks and I will look forward to our gym sessions together.

Best wishes,

Diana Perriman

C6. Letter to stroke subjects randomised to postural re-education only (PED group)

GROUP B

You have been randomised to Postural Education with a Physiotherapist

Could I ask you to phone **Physiotherapist Christine O'Brien on 6288 0601** to make an appointment. If nobody is home please leave a message with a name and contact phone number and Chris will get back to you.

Christine has been asked to assess your posture and review you twice over the next 12 weeks. YOU ARE NOT EXPECTED TO PAY A FEE. The invoice will be sent directly to us. The physiotherapy sessions are <u>specifically</u> for assessment and advice about your posture. The physiotherapist will have limited time and unfortunately will not have time to advise on other problems during these 3 sessions.

These physiotherapy sessions will take place in the **same place as your assessment here at the hospital**. If you require another map to guide you please ring Kristie or Kylie, our office managers on 62443858 and they will email or post one out.

One of our team will ring you to arrange the date for your 12 week assessment in the next couple of weeks.

Many thanks once again for taking part in this study. I hope you will enjoy the next 12 weeks and I will look forward to seeing you at your 12 week assessment.

Best wishes,

Diana Perriman

Appendix D – The Rankin Scale of stroke severity

The Modified Rankin scale which was administered over the phone to determine the severity of stroke immediately following the insult and at the time of interview.

KYPHOSIS STUDY BASELINE DATA COLLECTION FORM

Modified Rankin Scale Structured Interview (MRSSI)

0 *No symptoms at all; no limitations and no symptoms.*

1 ***No significant disability; symptoms present but not other limitations.***
Question: Does the person have difficulty reading or writing, difficulty speaking or finding the right word, problems with balance or coordination, visual problems, numbness (face, arms, legs, hands, feet), loss of movement (face, arms, legs, hands, feet), difficulty with swallowing, or other symptom resulting from stroke?

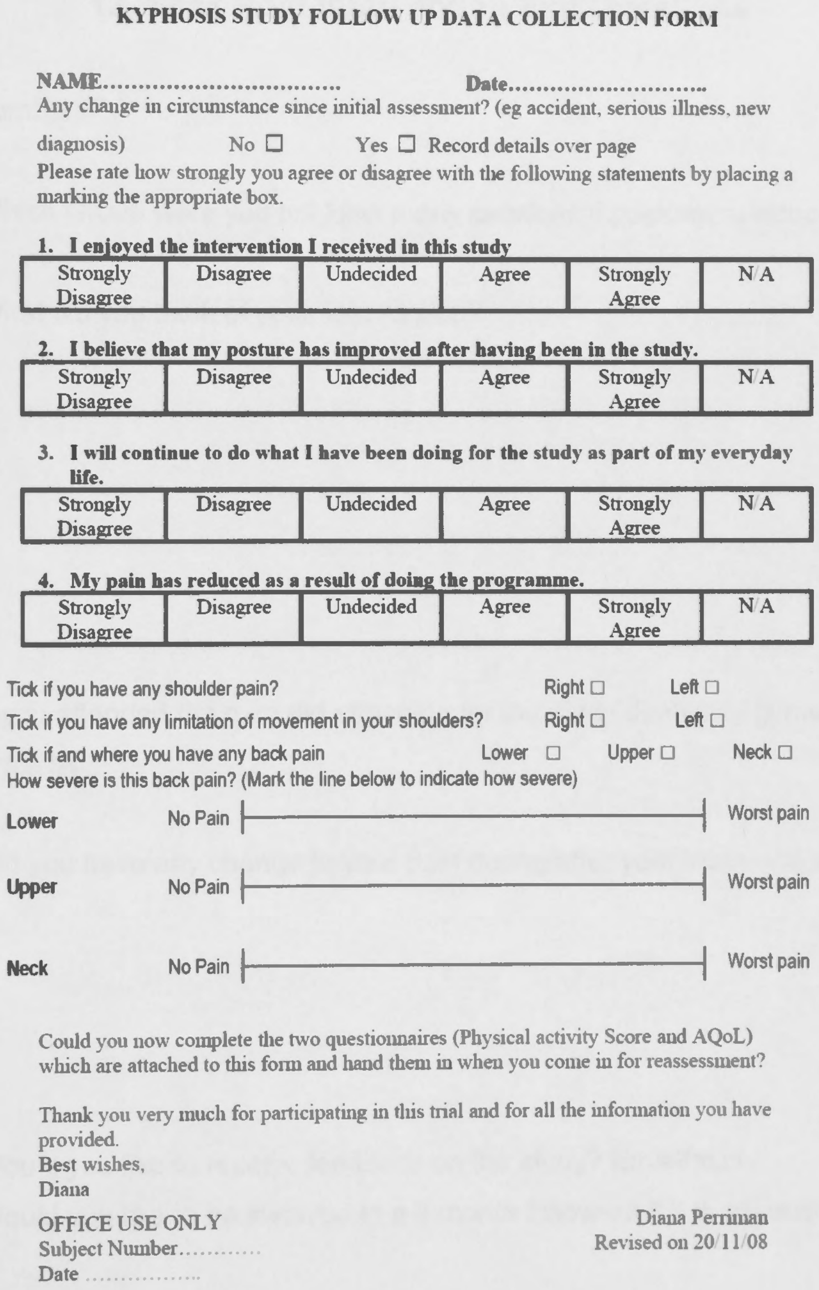
2 ***Slight disability; limitations in participation in usual social roles, but independent for ADL.***
Questions: Has there been a change in the person's ability to work or look after others if these were roles before stroke? Has there been a change in the person's ability to participate in previous social and leisure activities? Has the person had problems with relationships or become isolated?

3 ***Moderate disability; need for assistance with some instrumental ADL but not basic ADL.***
Question: Is assistance essential for preparing a simple meal, doing household chores, looking after money, shopping, or traveling locally?

4 ***Moderately severe disability; need for assistance with some basic ADL, but not requiring constant care.***
Question: Is assistance essential for eating, using the toilet, daily hygiene, or walking?

5 ***Severe disability; someone needs to be available at all times; care may be provided by either a trained or an untrained caregiver.***
Question: Does the person require constant care?

Appendix E – The follow-up data collection form with the Likert scale of subjective outcomes



KYPHOSIS STUDY FOLLOW UP DATA COLLECTION FORM

NAME................................ **Date**...........................

Any change in circumstance since initial assessment? (eg accident, serious illness, new diagnosis) No ☐ Yes ☐ Record details over page

Please rate how strongly you agree or disagree with the following statements by placing a marking the appropriate box.

1. I enjoyed the intervention I received in this study

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	N/A

2. I believe that my posture has improved after having been in the study.

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	N/A

3. I will continue to do what I have been doing for the study as part of my everyday life.

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	N/A

4. My pain has reduced as a result of doing the programme.

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	N/A

Tick if you have any shoulder pain? Right ☐ Left ☐

Tick if you have any limitation of movement in your shoulders? Right ☐ Left ☐

Tick if and where you have any back pain Lower ☐ Upper ☐ Neck ☐

How severe is this back pain? (Mark the line below to indicate how severe)

Lower No Pain |————————————| Worst pain

Upper No Pain |————————————| Worst pain

Neck No Pain |————————————| Worst pain

Could you now complete the two questionnaires (Physical activity Score and AQoL) which are attached to this form and hand them in when you come in for reassessment?

Thank you very much for participating in this trial and for all the information you have provided.

Best wishes,

Diana

OFFICE USE ONLY

Subject Number...........

Date ....

Diana Perriman

Revised on 20/11/08

Appendix F – The responses to the RCT exit questions

F1. The form used to collect the 12 week exit question information.

12 Week Post Intervention Exit Questions

Name:
Study Number:
Date:

1. Which Group were you in? How many sessions if postural re-education?
2. What did you think of your intervention?
3. If you attended the gym did attending for the study demystify gyms for you? Yes/No/NA
4. Did you have any change in your pain during/after your intervention?
5. Would you like to receive feedback on the study? Email/mail
6. Would you like to be involved in a 6 month follow-up if it is conducted?

Note This form was administered by the trial co-ordinator.

F2. Responses from normal subjects who received both strengthening and postural re-education (BOTH group)

N2

Q2. What did you think of your intervention/s?

Physio – Odd, found a lot of posture problems had lots of exercises which he did. Arm elevation back against the wall but gave upper arm problems. Gym – easy,

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Physio helped – yes more conscious of how sit and stand control of rib cage. Gym – didn't notice any difference to strength.

N6.

Withdrew

N11

Q2. What did you think of your intervention/s?

Physio – great. Made me look at myself and how I stand and do things. "You have perfect posture" comments from work x 3. Gym programme – good, manageable until the very end.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Used to have hip pain with referred to knee. Now no but MBTs one posture study.

N14

Q2. What did you think of your intervention/s?

Fantastic. Made me more conscious of poor posture. Better posture in car. Physio advice very helpful. Gym – enjoyed very much. Going to go to the gym again next year.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

No.

N19

Q2. What did you think of your intervention/s?

Enjoyed going to the gym. Was happy with the frequency. Got me going in the day.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

No pain before or after. Now change otherwise.

N23

Q2. What did you think of your intervention/s?

Super. Gym – became a welcome discipline. Really looked forward to it. Motivated to improve performance after each gym session. Felt exhilarated and motivated to start. ANU staff very interested and helpful. Physio sessions x 2 – found out a lot of things about how he held his head and posture. Also interesting thing – on first posture review was having pins and needles in lateral fingers of both hands due to hyper extension of upper neck, has stopped doing it and has no pins and needles. Enjoyed programme very much and is now motivated to do more.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Yes. Pain reduced markedly.

N28

Q2. What did you think of your intervention/s?

OK. Gave good exercises but already knew these. Massage but not so good. Soft tissue massage and stretching but there are alarms on computer to remind stretches. Now looser anteriorly.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Maybe a bit less stiff.

N31 - Withdrew

N34

Q2. What did you think of your intervention/s?

Gym – fine 3 x per week difficult especially when closed for business. Occasional low back pain with exercises (last set 10) but improved. Physio – no pressure to do exercises so was irregular until met other participants which encouraged. Sheet Di gave me were what we did at gym except pulling shoulders back and down and pulling chin in. Expected more measurement but enjoyed having information especially “core stability” NB went away for 5. Confounder could have be own gym programme was stepped up. Now more aware of posture in normal life. More aware of slumpy posture when tired.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

No. No previous pain.

N39

Q2. What did you think of your intervention/s?

Physio – useful, 4 mins work on back and hamstring but forget to do exercises. Gym – debatable whether achieving anything? Not enough resistance. No effect on position sense.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

No real change in neck and low back pain.

N44

Q2. What did you think of your intervention/s?

Physio: Quite easy. Easy exercises, no problem, easier than going to the gym and did them the appropriate number of times.

Gym: 'Worked me a bit'. – especially on concentrating on getting it right. Felt more aware of body after doing resisted exercise but seeing the physio helped to clarify where body should be.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Low back pain unchanged. Sitting slumped in the evening might make it worse. Bending and working in the garden makes it worse.

N46

Q2. What did you think of your intervention/s?

Physio – Very good. Surprised Liz thought her posture was good. Exercises were practical and good but remembering to do them was hard. Now is going to try to do them more. Gym – Made me feel good for doing them but pain to do them and concerned about petrol costs. Very conscious that walked out more upright feeling younger and more buoyant. Relieved it was over. Combined – Heightened awareness to posture. Best advice from Liz to pull shoulders up "hook" and over – wonderful.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Yes. Neck and shoulder pain bad at the moment because of moving classroom and report writing.

N49

Q2. What did you think of your intervention/s?

Physio – x 2 exercises were good and one was painful. Did exercises every day. Stretching exercise was difficult. 2 of the 4 exercises were excellent. Felt better after doing exercises. Back felt stronger and more erect. Gym – fine. Lower back was a bit tender to start but fine after a while. Definitely stronger and generally easier to stay more straight. Gym probably more effective but physio exercises more portable.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Yes. Low back is definitely better - related to mobility.

N56

Q2. What did you think of your intervention/s?

Physio – really interesting because gave me some great tips like adjusting shoulders so they hang further back. Made me think about posture more. NB: Physio noticed a change in the strength of the thoracic spine with gym work. Gym – Just go in and do it. Eventually did it “mindlessly” upped weights but not too much, didn’t want to over do it. Parking difficult often work but feel much stronger across the back. Posture feels different because she knows more and thing about posture more. Stronger lifting things off shelves at work.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

No. But looser in the neck than previously.

N59

Q2. What did you think of your intervention/s?

Physio – Picked up on poor abdo control after x 3 sessions. Doing those but finds it is hard to fit in all the exercise into everyday life. Feels that they would like core strengthening exercises in standing or sitting rather than lying which is hard to remember. Gym – Doing the exercise was easy but would have preferred 2 activities rather than just one for convenience if someone else using the equipment and for variety. Getting there 3 x per week not too onerous.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

N/A

Summary: Gym exercise made people stronger and some had a better sense of being upright but it was a lot to expect X3 per week. No really sustainable by the majority. The physio advice was very helpful and sometimes resulted in decreased pain and pins and needles. The exercises were most useful when they were performed in functional positions like sitting and standing.

F3. Responses from normal subjects who received postural re-education only (PED group)

N3

Q2. What did you think of your intervention/s?

No response

Q4. Did you have any change in you pain during/after your intervention/s? Details?

No response

N8

Q2. What did you think of your intervention/s?

Good, Worthwhile, more conscious of posture and being more upright. Feel much more aware.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Has a history of LBP but has non in the past 12 weeks. Able to lie flat on floor more easily.

N12

Q2. What did you think of your intervention/s?

Push shoulders back and make double chin several times a day – actually managed once a day. Didn't notice a difference.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

No change in pain except back ached more than usual after lifting

N13

Q2. What did you think of your intervention/s?

Demanding. 10 x 10 secs x 6 times per day. Lots of retraction. Lying on a towel. Lay horizontally. Managed daily.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Initially pain increased but now it has reduced. Will continue exercises but not 6 x day. Probably just morning and night. Standing straighter. More aware of ? back.

N20 - Withdrew

N24

Q2. What did you think of your intervention/s?

Very good, useful. Feels better. More conscious of posture. Feels posture has altered. Exercises = advice re alignment. Shoulder retraction/extension against the wall, lying on ground.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

No

N25

Q2. What did you think of your intervention/s?

Very Informative – Exercises and noticed a difference in posture. Also has a heel wedge on the left. Ex Prog – Roll shoulders back in chair. Lying on floor with towel (stretch). Transversus exercises. Sit ups (strengthening abdo). Enjoyed advice and tends to roll shoulders back when walking. “No way I would have gone to a physio unless I had pain i.e.something wrong.”

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Yes. Low back pain increased? Due to a V.T.I. 8 going to physio upped the pain.

N30

Q2. What did you think of your intervention/s?

Got a lot out of going to physio. Breathing better. No longer getting abdo pain, gassy and tight!! Jaw pain has gone, not grinding teeth. Neck range has improved markedly, hasn't been able to turn head for 20yrs. Breasts feel less floppy and feels pectorals are getting stronger, moving more freely, AMAZING!

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Yes. Jaw, abdom, toe, headache.

N33

Q2. What did you think of your intervention/s?

Exercises good but complained not much wrong. Not too good at doing it.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

N/A

N40

Q2. What did you think of your intervention/s?

Exercises were excellent. Will go back to see him. Feels posture not as good because of the fall which stopped doing some exercises and neck felt stiff.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

No previous pain.

N42

Q2. What did you think of your intervention/s?

Fascinating. Didn't think much was wrong. Exercises – standing doorway pec stretches. Chin in (deep neck flexes). Core stability – abd twice a day. Exercises helped and I am more aware of posture and opening out chest and neck position. Low back has improved over the time.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Low back has reduced but otherwise not.

N47

Q2. What did you think of your intervention/s?

Advice and exercises. Corrected position of shoulders and neck. Quite informative. No negatives. Feels posture is better.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

No pain to start with.

N52

Q2. What did you think of your intervention/s?

Didn't tell me anything I didn't know. Gave an IJB stretch and some simple extension exercises – hasn't been doing them much.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

No change as a result of seeing physio.

N54

Q2. What did you think of your intervention/s?

Gentle informative. The exercises were doable but couldn't do pu. Exercises were tedious. Expected to do daily or 1-2 X per day. Some of the exercises she did frequently through day, others only did 3-4 X per week. – Aimed to do exercises but didn't get around to it. The ones she did frequently would be the ones she could fit into normal life. Informative in terms of understanding how to focus on being straight particularly upper back / shoulder neck. So more aware of posture than before. Helpful to discuss continued practice and fitting into daily life in last session.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

No.

N60

Q2. What did you think of your intervention/s?

Good. Realised that advice wasn't all very useful. i.e. Quads tight – major reason for slumped posture. 1. Sit down shoulders back chin in 5 X day – could do that. 2. Quad stretch 5 X day actually di it X 1 per day then dropped completely. 3. Back arches in chair – didn't do much. Measured how far could lean forward also lunges (why?). Physio felt had lordosis which along with tight quads was causal. Felt that tucking chin in and pulling shoulders back was most helpful – still doing this.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Yes. Neck pain seems to have disappeared.

Summary: Generally very positive with noticeable improvements in body awareness and posture. Lack of compliance when exercises were deemed not to be directly relevant eg quads stretches or too many eg expected to do them X6 per day. Over all though the paprticipants were very positive and learned a lot. Pain has decreased and less stiff.

F4. Responses from the normal subjects who received strengthening only (STR group)

N1

Q2. What did you think of your intervention/s?

Good for me, though I did have trouble getting there.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Yes ached for several days, started when dipping. Pain on the right side when lifting arms above head has gone – can now reach clothesline.

N5

Q2. What did you think of your intervention/s?

Enjoyed the gym but the distance had to travel was sometimes difficult. The exercise was easy and it is an exercise I would choose if available in the gym. Now attending another gym – probably developed the incentive from being in the study.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Yes. Back pain much reduced and able to stand for much longer without support. Catholic priest so ceremonies like confirmation can sometimes take several hours. In the past was looking for a seat because of pain and discomfort. Now not. Also the parishioners have commented on how much straighter he looks.

N9

Q2. What did you think of your intervention/s?

Good – never been to a gym before and I was enlightened by the experience. Felt stronger in the trunk especially abdominals.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Has had back pain for years and has worsened in the past 12 months. Pain has been noticeable over past 2 weeks (low back pain).

N16

Q2. What did you think of your intervention/s?

Programme good. Went every week until hurt back and stopped but went back and was fine. Found 3 x per week hard only at end when was unwell.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Developed back problems at end due to another incident but felt better from exercises. More upright and strong and walking better.

N18

Q2. What did you think of your intervention/s?

12 week program good. Helped. More aware of standing up. More aware of posture.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Get upper back pain.

N22

Q2. What did you think of your intervention/s?

Just did it to help with the study. Interesting watching other people in gym.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

No pain.

N26

Q2. What did you think of your intervention/s?

Good, motivational. Grew to like the machine. Back felt stronger with exercise.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

No pain before.

N32

Q2. What did you think of your intervention/s?

Fine. Worked well, no great inconveniences. Staff pleasant, good access to machine.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

No Pain before.

N35

Q2. What did you think of your intervention/s?

Enjoyed it. Don't know if it helped posture – didn't discern any change. Gym staff fine. Introduced you to a gym and broke barriers.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

No Pain previous.

N38

Q2. What did you think of your intervention/s?

Good – Sometimes frustrating ANU 3 times per week. Exercise was good. Feels stronger but not noticeably.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

No pain beforehand but has low back pain when doing exercise. Had LBP doing to back exercise but didn't persist. Same as pre existing.

N43

Q2. What did you think of your intervention/s?

Became a challenge to do it properly. Found the gym good, better than expected. Left him alone and friendly and courteous. Made me more aware of posture so think more about posture in sitting and standing. Haven't really noticed any difference in general day to day activities.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

N/A

N45

Q2. What did you think of your intervention/s?

Enjoyed it. A couple of times felt boring but overall good. Feels withdrawal symptoms since finished.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Neck pain related to acoustic neuroma operatic. Gets some after sweeping. No change in prog.

N50

Q2. What did you think of your intervention/s?

Good, became more challenging as can hit a golf ball further. Feels posture better – feels stands up better. No remarks from friends though. Feels stomach is flatter and stronger.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

No pain.

N55

Q2. What did you think of your intervention/s?

Not sure if the gym exercise helped but it should have. Not sure if in the long term any difference will be maintained. A lot of commitment and had to make a big effort, parking very difficult.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

N/A

N57

Q2. What did you think of your intervention/s?

Really good, easy to do, enjoyable. Got better at using the equipment. As time went on got better at the end movement position also not sure the weight. If too much weight didn't feel as tall walking out – needed to be the right weight. Important that I checked. Now have more of a sense of body position than before. Didn't like being with a younger cohort – different vibe and music.

Q4. Did you have any change in you pain during/after your intervention/s? Details?

Yes. Low back pain feels better since exercises. Feels better – probably stronger, would like to do a full programme, feels more confident.

Summary: The subjects who attended the gym enjoyed feeling stronger and noticed improvements in some functional activities such as playing golf. They didn't feel an overt change in their posture although one subject commented that if they put too much weight on the machine they didn't feel as tall when they walked out! Getting to the gym was often difficult but mainly because of the parking. Some complained of low back pain during the exercise which did not persist.

F5. Responses from stroke subjects who received both strengthening and postural re-education (BOTH group)

S3

Q2. What did you think of your intervention/s?

Thought it was fantastic. Had to have a break because of the hot weather and was happy to have extra time at end. Now know how to hold self whereas before didn't. Both were beneficial but can continue doing physio exercises at home not going to stop. Gym – fun, feels stronger now than before. Still not well balanced.

Q4. Did you have any change in your pain during/after your intervention/s? Details?

N/A

S6 - Withdrew

Summary: Only one respondent. Enjoyed the gym and felt more control from it but both were beneficial.

F6. Responses from stroke subjects who received postural re-education only (PED group).

S1

Q2. What did you think of your intervention/s?

I really enjoyed it. I am much more aware of my posture now than before. I feel I am standing straighter.

Q4. Did you have any change in your pain during/after your intervention/s? Details?

No.

S7

Q2. What did you think of your intervention/s?

Christine was excellent. She would work out exactly what was wrong and understood that it could become boring. Not very good at exercising which is why I go to the gym. Traqus to wall measurement improved neck retract exercises really helped. Heels against wall made back ache. Physio made a difference.

Q4. Did you have any change in your pain during/after your intervention/s? Details?

Yes. Neck pain reduced, gone (can control it). Could have been massage or exercises. Low back pain comes on when doing posture exercises but goes away.

S10

Q2. What did you think of your intervention/s?

Fruitful – Chris got me into the falls prevention clinic – useful because it confimrd what I knew about my condition. Given exercises by falls clinic to do. Overall falls clinic confirmed own understanding of limitations but perhaps not what

I'd hoped for. Chris's intervention – Interupted by admission to Calvary for a small bowel obstruction and visit to demented wife in hospital. So motivation lacking. "I know I have a posture problem but I tend to ignore it". So not very motivated to do exercises, probably more motivated in a group.

Q4. Did you have any change in your pain during/after your intervention/s? Details?

No.

S13

Q2. What did you think of your intervention/s?

Pleased to have physio at home. She liked to see the place where doing exercises. Felt having exercises at home was a great idea. The exercises were good most difficult part – getting out of bed after. Stretch in supine hands, rolling, stretching arms back in stand thinking about posture, standing against the wall pulling chin in. Feels posture has changed for the better. Also leaning to Right – need to put shoulders over hips.

Q4. Did you have any change in your pain during/after your intervention/s? Details?

Did have a twinge in right hip which went altogether and came back recently.

Summary: Overall positive with the advantage of having a health professional to help key the patient into other services e.g falls clinic. One comment that group exercise might be more beneficial for one subject.

F7. Responses from stroke subjects who received strengthening only (STR group)

S2

Q2. What did you think of your intervention/s?

Enjoyed gym. Movement more flexible.

Q4. Did you have any change in your pain during/after your intervention/s? Details?

No pain but movement seems better. No change in TF's or in bed.

S9

Q2. What did you think of your intervention/s?

Quite enjoyed it. Enjoyed getting out of the house and having something to do because the gym session was free and open access times could fit it in with bus timetables, Drs and other errands. The exercise itself was quite enjoyable but not hard enough – feels he need to do more (part of personality). Downsides – when it rained but otherwise none really.

Q4. Did you have any change in your pain during/after your intervention/s? Details?

Yes. Felt his hamstrings when first started but stopped after a while. (stretch). Function: Noticed that he has changed sitting position – not comfortable in slumped position anymore. More comfortable in an upright position.

S11

Q2. What did you think of your intervention/s?

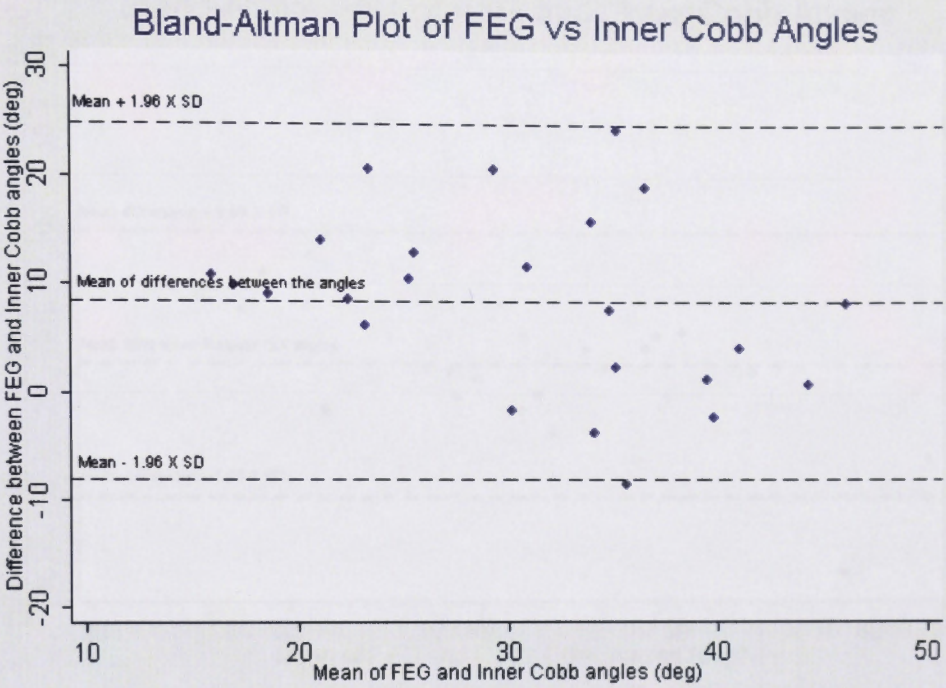
Enjoyed going to the gym and the exercise made me use my back and tummy.

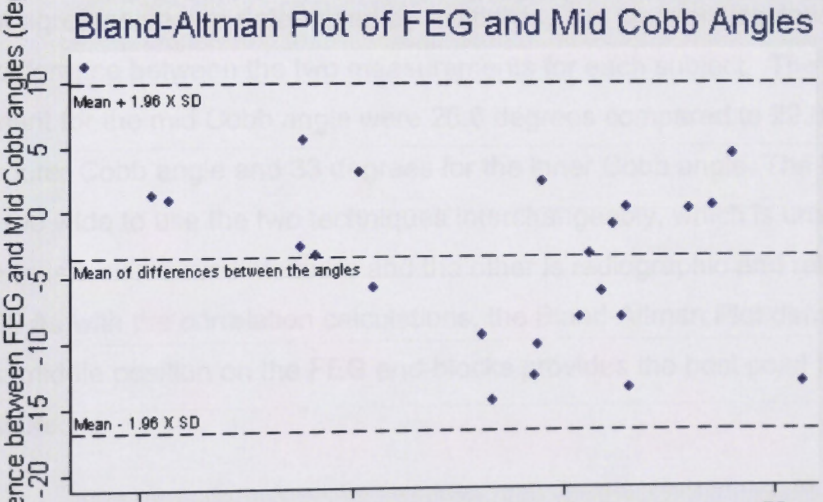
Q4. Did you have any change in your pain during/after your intervention/s? Details?

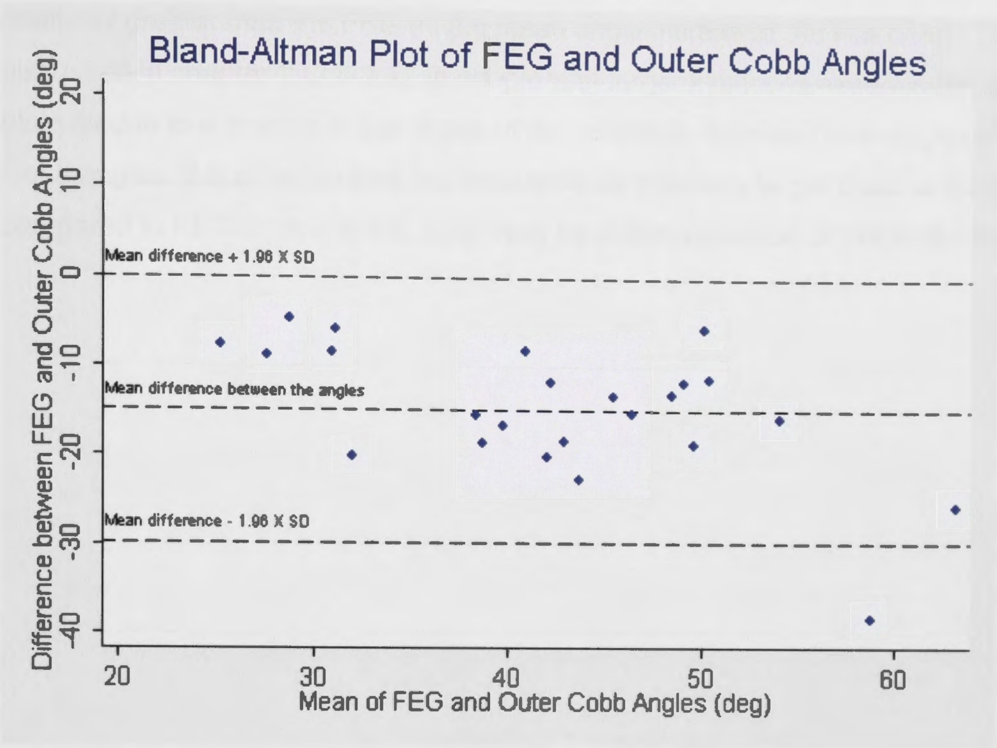
No change in LBP.

Summary: All subjects enjoyed the gym intervention because it improved the control of their trunk in general. Getting there didn't seem to be a problem.

Appendix E – The Bland Altman Plots







Bland-Altman plots were constructed to investigate the agreement between the FEG measurements and the inner, mid and outer Cobb angle measurements. The limits of agreement were determined by multiplying the standard deviation of the mean difference between the two measurements for each subject. The limits of agreement for the mid Cobb angle were 26.6 degrees compared to 29.8 degrees for the outer Cobb angle and 33 degrees for the inner Cobb angle. The limits are clearly too wide to use the two techniques interchangeably, which is unsurprising, since one is a skin-based measure and the other is radiographic and relies on end plate tilt. As with the correlation calculations, the Bland-Altman Plot demonstrated that the middle position on the FEG end-blocks provides the best point from which to measure.

The distribution on the Bland Altman plot reveals a bias for each of the measures with the inner, mid and outer Cobb mean difference being + 8.4 degrees, -3.5 degrees and – 14.9 degrees. The distribution of the points indicates a negative trend in the difference between the FEG and Cobb with an increase in the magnitude of the mean angle. This indicates that the Cobb angle tended to be relatively greater than the FEG as the mean angle increased. As has been discussed in chapter 2 (2.6.2.1), in people with larger kyphoses exaggerated end-plate tilt due to a change in the shape of the vertebrae may lead to exaggerated Cobb angles. It is possible that the trend towards relatively larger Cobb angles compared to FEG angles in this study may be a demonstration of this problem.

From: Leigh Jarvis <Leigh.Jarvis@psa.org.au>
Subject: **Fwd: Vic & ACT re-prints**
Date: 20 October 2011 4:55:01 PM AEDT
To: Bruno Dalla Venezia <sales@xibit.com.au>
▸ 1 Attachment, 3.1 KB

Hi Bruno.

Here are the details for the VIC drop off on saturday. (see below).

Also with the reprinted books for NSW, can i have 10 of them delivered to me here before next weekend? The other 43 copies can then be delivered to NSW before the 19th (they are needed on the 19th for the event so they need to be there earlier).

The rest for the other states as planned.

Cheers bruno!

Leigh

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Begin forwarded message:

From: Deborah Benjamin <deborah.benjamin@psa.org.au<mailto:deborah.benjamin@psa.org.au>>
Subject: Vic & ACT re-prints
Date: 20 October 2011 4:47:15 PM AEDT
To: Leigh Jarvis <Leigh.Jarvis@psa.org.au<mailto:Leigh.Jarvis@psa.org.au>>

Hi Leigh,

Hilja will take shipment of the mini booklets (x50) her details are:

Hilja Toom
52 Hammond St
Altona VIC 3018

Home phone: 03 9398 1321
Work phone: 03 9389 4000

With the ACT booklets (x10), could the printers give these to you to give to Caroline Khalil or Catherine Waterman ready for next weekends workshop. The workshop is being held in the PSA boardroom.

Regards.

Deborah Benjamin
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