Quantifying variation of paediatric patient length of stay among Australasian intensive care units

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ABSTRACT

OBJECTIVE: To quantify variation of mean paediatric patient length of stay (LoS) among intensive care units (ICUs) in Australia and New Zealand

METHODS: Retrospective data from Australian and New Zealand institutions with paediatric ICU admissions were analysed. The data were collected between 1997 and 2006 providing a total of 123 institution years of data (an average of 6.15 years per site). Patient LoS was modelled as the outcome variable of a gamma regression with patient risk factors entered as fixed effects (allowing adjustment for case mix) and variation among ICUs modelled using a random effect.

RESULTS: Six Australasian ICUs had an average risk-adjusted paediatric LoS which was significantly shorter than average, while five had an average LoS that was significantly longer than average. The remaining nine sites had average LoS that were not significantly different from the average (at the 95% level). Among other risk factors, previous admission to an ICU and respiratory support within the first hour of admission were both associated with prolonged LoS.

CONCLUSION: There was significant variation in paediatric patient LoS at the ICU level not accounted for by patient case mix. This has important implications for efficiency of ICU processes and, possibly other parameters of quality of patient care in those institutions with longer LoS.
INTRODUCTION

Increasingly, health care providers are interested in reliably measuring their performance and quality of patient care [1, 2]. To review quality of care, quantifiable indicators must be identified and measured [3, 4].

The importance of length of stay (LoS) as a performance indicator in the intensive care unit (ICU) is two-fold. Firstly, it relates to the efficiency of the intensive care process, and thus cost within the ICU and the institution overall. According to a US study ICUs comprise 10% of hospital beds but they consume around 20% of a hospital’s budget [5]. The majority of the cost associated with ICU patients is related to nurse time required for patient care, which is a direct function of patient LoS [6]. Secondly, it may serve as an indirect marker of the quality of care; more effective therapy results in more rapid recovery while complications and errors potentially result in extended LoS [4, 7, 8].

For objective comparison of performance among institutions, outcomes such as LoS, there is a requirement to adjust for patient case mix [9-11]. Risk-adjustment models can be employed to account for much of the variability in patient case mix as well as other admission factors, such as source of admission, and used to obtain reasonable estimates of the effect of the institution on patient LoS. Quantification of institution-level variation of patient LoS among ICUs has important implications for health care management. In particular, it can serve as a tool for recognition of potentially inefficient practice and sub-optimal quality of patient care.
The aim of this study is to quantify the variation of mean paediatric patient length of stay (LoS) among intensive care units (ICUs) in Australia and New Zealand.

**METHODS**

**The data:**

The Australian and New Zealand Paediatric Intensive Care (ANZPIC) Registry collects data from the 9 dedicated paediatric ICUs (PICUs) in Australia and New Zealand and paediatric data from multiple general ICUs that accept paediatric admissions. Data from eleven of these general ICUs, plus the 9 PICUs, were included in this analysis. The registry comprises patient de-identified records stored in a Microsoft Access database and complies with the minimum guidelines for health registers, as developed by the National Health Information Management Group (NHIMG). Patient data are extracted from source data by individual ICU nurse researchers or data managers and submitted to the central registry. All data are subjected to quality checks before being approved as cleaned and uploaded into the registry. To improve data integrity further, and to reduce inter-rater discrepancy, ICUs have periodic external auditing of a random selection of source records, and data collectors participate in training sessions provided by the registry.

Cleaned data from all Australian and New Zealand ICUs participating in the Registry were analysed. The data were collected between 1997 and 2006, providing a total of 123 institution years of data, (an average of 8.67 years per paediatric ICU and 4 years per general ICU). In Paediatric ICUs, the average number of children admitted per
year per facility ranged from 320 to 1121 admissions. In General ICUs, the average number of admissions per year per facility ranged from 8 to 143 admissions.

**Inclusion criteria:**
The records of all admissions to ICUs participating in the ANZPIC Registry were extracted. For inclusion in the study, patients must have been aged less than 16 years at time of admission.

Mean LoS in the ICU might be confounded by patients who die. Given short LoS is considered as a marker of efficiency, patients who die quickly within the ICU may provide false evidence of efficiency. Patients who die in the ICU represent a distinct population that warrant separate investigation and modelling approaches. For these reasons, children who died in the ICU were excluded from this study.

Children with a LoS less than 2 hours were excluded as it was considered that these did not represent true ICU stays. In addition, those children who were recorded as still in ICU or who were transferred to another ICU were excluded from this analysis as their LoS could not be reliably quantified. Finally those children staying longer than 28 days (<1%) were excluded as these may unduly influence model parameter estimates [12, 13].

**Variable Selection:**
The variables used are described in Table 1. Univariate analyses were performed to identify risk factors associated with LoS using the Mann-Whitney U test for binary variables [14] and univariate gamma regression for categorical and continuous
variables. Risk factors with an associated $p$ value $<0.2$ were included in the multivariate analyses. Only variables present in at least 90% of patients were considered for inclusion in the model.

Table 1. Description of variables in the Australian and New Zealand Paediatric Intensive Care Registry.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Variable Description</th>
<th>Variable Type</th>
<th>Missing values (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICU Length of Stay</td>
<td>Patient length of stay in ICU measured in days</td>
<td>Continuous</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Respiratory Support in the first hour</td>
<td>Mechanical respiratory support given within the first hour of admission (0/1; no/yes)</td>
<td>Binary</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Elective Admission</td>
<td>Was the admission elective? (0/1; no/yes)</td>
<td>Binary</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Retrieval</td>
<td>Patient required specialist retrieval team? (0/1; no/yes)</td>
<td>Binary</td>
<td>43 (0.1)</td>
</tr>
<tr>
<td>Systolic Blood Pressure</td>
<td>Systolic Blood Pressure at admission (mmHg)</td>
<td>Continuous</td>
<td>4025 (7.9)</td>
</tr>
<tr>
<td>Age</td>
<td>Age in years at admission (e.g. 18mth old has age=1.5)</td>
<td>Continuous</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Pupils</td>
<td>Fixed and Dilated Pupils at admission? (0/1; no/yes)</td>
<td>Binary</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Principal Diagnosis</td>
<td>ANZPIC diagnostic coding</td>
<td>Categorical</td>
<td>5 (&lt;0.1)</td>
</tr>
<tr>
<td>Recovery</td>
<td>Recovery from a Procedure? (0/1; no/yes)</td>
<td>Categorical</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>ICU Admission Source</td>
<td>(1) Direct ICU admission; (2) Operating theatre or recovery; (3) Emergency Department; (4) Ward; (5) other ICU or NICU (same hospital), (0) No; (1) Yes , readmitted &lt;48 hours post discharge; (2) Yes , readmitted &gt;48 hours post discharge</td>
<td>Categorical</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Previous Admission</td>
<td></td>
<td>Categorical</td>
<td>43 (0.1)</td>
</tr>
</tbody>
</table>

The children’s principal diagnosis at admission was assigned using the ANZPIC Registry diagnostic coding which has been previously described[15]. Given LoS is approximately lognormal, for this variable, the geometric mean LoS for each diagnostic code was determined and the conditions were grouped into quintiles. The ANZPIC Registry diagnostic coding has been provided as an appendix with the diagnostic grouping information and geometric mean LoS for each condition.
Model Development:

The data were split using stratified random sampling (with the ICU as the stratum) into two subsets to be used for model building and validation. The skewed distribution and heterogeneity of LoS, see figure 1, poses difficulty for statistical modelling[16]. The Gamma distribution has been shown to be suitable for modelling LoS [17, 18]; it is a two parameter probability distribution governed by a shape and scale parameter[19]. A gamma distributed variable with scale $\theta$ and shape $k$ is denoted by $\Gamma(k, \theta)$, where the mean is $k\theta$, the variance is $k\theta^2$ and the probability density function is given by

$$f(x) = \frac{x^{k-1}e^{-x/\theta}}{\theta^k \Gamma(k)}$$

The relationships between patient LoS and associated risk factors were modelled by a gamma mixed effects regression, where $\log(E(Y))$ is modelled as a linear function of the covariates. To quantify variation among ICUs, random effects ($u$) for each site were incorporated into the model. Unlike a fixed effect, the random effect’s value varies depending on the site and estimates the ICU-effect on LoS after adjusting for patient factors. Let $Y|x_{ijk}$ represent the ICU LoS for the $j$’th patient in the $k$’th ICU where $i$ represents the $i$’th covariate (1, 2, 3, …, 20).

$$\log[E(Y \mid x_{ijk})] = \beta_0 + \beta_i x_{ijk} + u_k$$
All potential variables were inserted into the saturated model and backward elimination was used with an exit criterion of \( p > 0.05 \). Gender was eliminated during this process, with all remaining predictor variables being significant.

The complete data set (including building and validation subsets) was used for the final model. Complete-case analysis utilised 47,068 observations (of 51,125)

**Validation**

Internal validation was used to assess the performance through application of the model derived from the building sample to the validation sample. In the manner of Tu and Mazer [20], the discriminatory capability of the model was assessed using a receiver operating characteristic (ROC) curve. Observed LoS, dichotomised at the median (1.125 days) was taken as the comparison variable and area under the ROC curve (AUC) of >0.7 was considered to indicate acceptable discriminatory performance [21]. Lin’s concordance correlation coefficient was used to quantify the correlation between the observed and predicted values at the individual patient level. The concordance correlation coefficient (CCC) measures the strength of agreement along the identity line, whereby 1 indicates perfect agreement and -1 indicates perfect disagreement [22]. The distribution of the observed and predicted LoS is shown in figure 1. An adjusted pseudo R2 for was calculated using a method for gamma models that has been described by Mittlbock and Heinzl [23].

**RESULTS**
The building model gave reasonable estimations of the mean LoS for sites in the validation set. The AUC was acceptable at 0.809 (95% CI: 0.803-0.814). However, the concordance correlation between the predicted and observed LoS in the validation sample was modest at 0.38\[22\]. These results suggest that the model had acceptable performance in discriminating between LoS that were shorter and longer than the median but was less effective in predicting the actual LoS. The pseudo R² for the final model was 0.49.

Figure 2 presents box plots of the observed and predicted distributions of LoS by facility. The outliers have been excluded from the graph to improve clarity. In every case the predicted median is higher than the observed. This is due to the presence of long stay outliers in the observed not being well predicted by the model. Given the model is fitted to the mean there is a shift in the distribution of

The final model is presented in table 2. Notable factors associated with prolonged LoS were previous admission to an ICU and respiratory support within the first hour of admission. Both are indicative of a more severe or complex patient condition. The multiplier effect of each variable on a child’s LoS is indicated by \(\exp(\beta)\). The random intercepts for ICU site were estimated by the final model and the antilog of the random effect for each ICU are presented with 95% confidence limits in figure 3. The site effect has a multiplier effect on mean LoS; a site effect of 1.5 indicates that patients are, on average, likely to stay 1.5 times longer than would be expected compared to the risk-adjusted mean LoS for the total population.
Table 2. A mixed effects gamma regression model of patient length of stay in intensive care units receiving paediatric admissions in Australia and New Zealand, 1997-2006.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Coefficient (β)</th>
<th>95% CI</th>
<th>Exp(β)</th>
<th>Pr &gt;</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory Support in the first hour (yes)</td>
<td>0.68</td>
<td>0.66, 0.69</td>
<td>1.96</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>Elective Admission (yes)</td>
<td>-0.19</td>
<td>-0.21, -0.16</td>
<td>0.83</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>Retrieval (yes)</td>
<td>0.08</td>
<td>0.05, 0.11</td>
<td>1.08</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>Systolic Blood Pressure (at admission)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBP (value)</td>
<td>-0.02</td>
<td>-0.02, 0.02</td>
<td>0.98</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>SBP² (value*value)</td>
<td>0.00</td>
<td>0.00, 0.00</td>
<td>1.00</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>Age (in years at admission)</td>
<td>-0.01</td>
<td>-0.01, 0.01</td>
<td>0.99</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>Pupils (yes, fixed and dilated at admission)</td>
<td>0.48</td>
<td>0.33, 0.64</td>
<td>1.62</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>Diagnostic Group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diagnostic Group 1</td>
<td>-0.58</td>
<td>-0.61, -0.55</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diagnostic Group 2</td>
<td>-0.27</td>
<td>-0.30, 0.25</td>
<td>0.56</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>Diagnostic Group 3 Reference</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diagnostic Group 4</td>
<td>0.29</td>
<td>0.27, 0.32</td>
<td>1.34</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>Diagnostic Group 5</td>
<td>0.58</td>
<td>0.54, 0.61</td>
<td>1.78</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>Recovery from a Procedure?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>Reference</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes, recovery from a bypass procedure</td>
<td>-0.16</td>
<td>-0.21, 0.12</td>
<td>0.85</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>Yes, recovery from other procedure</td>
<td>0.06</td>
<td>0.02, 0.09</td>
<td>1.06</td>
<td>0.0036</td>
<td></td>
</tr>
<tr>
<td>ICU Admission Source</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating theatre or recovery</td>
<td>-0.09</td>
<td>-0.13, -0.05</td>
<td>0.92</td>
<td>0.0003</td>
<td></td>
</tr>
<tr>
<td>Emergency Department</td>
<td>-0.06</td>
<td>-0.09, -0.02</td>
<td>0.94</td>
<td>0.0027</td>
<td></td>
</tr>
<tr>
<td>Ward</td>
<td>0.17</td>
<td>0.14, 0.21</td>
<td>1.19</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>Other ICU or NICU (same hospital)</td>
<td>0.28</td>
<td>0.15, 0.42</td>
<td>1.33</td>
<td>0.0002</td>
<td></td>
</tr>
<tr>
<td>Direct ICU admission Reference</td>
<td>Reference</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Previous Admission</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>Reference</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes, readmitted ≤48 hours post discharge</td>
<td>0.21</td>
<td>0.16, 0.26</td>
<td>1.23</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>Yes, readmitted &gt;48 hours post discharge</td>
<td>0.25</td>
<td>0.22, 0.29</td>
<td>1.29</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>1.79</td>
<td>1.62, 1.95</td>
<td>5.97</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>

After adjusting for patient characteristics at time of admission, several sites had significantly longer (sites P-T) or shorter (sites A-F) average LoS than the population.
mean. The remaining sites had an average LoS that was not significantly different from the population mean at the 95% level. The pattern of variation does not appear to be different among general and Paediatric ICUs.

DISCUSSION

ICU LoS can be estimated using gamma mixed effects modelling, with the random effect serving to quantify variation in patient LoS among ICUs. Our model revealed significant differences in risk-adjusted average LoS between ICUs receiving paediatric admissions in Australia and New Zealand.

The possible reasons for this variation in LoS are diverse. Firstly, LoS is affected by many intrinsic patient factors. While our model accounts for some of these, there may be variation in patient case-mix not explained by the variables available in our analysis. Secondly, the time of discharge for a given patient is based on a clinical assessment of patient risk; this decision will be influenced by variations in physician judgement. Thirdly, the availability of beds[24] and the level of care provided by post-ICU care facilities will affect discharge time. For example, the presence of a separate high dependency unit (HDU) in one hospital would likely bring forward the discharge time. Fourthly, the efficiency and efficacy of treatment will impact time to patient recovery and subsequent discharge[25]. A fifth consideration is that access to subspecialist services may be more limited in general ICUs compared to dedicated paediatric ICUs. Such access issues may result in discharge delays causing longer than expected length of stay. Lastly, adverse patient outcomes, such as healthcare-associated infections, are known to prolong hospital and ICU LoS[26].
Our model does not discriminate between these potential explanations, but does confirm that such variation exists and that further investigation is warranted. If it were determined that the availability of general ward beds when patients were ready for discharge, or that variability in physician practice were major contributors, then this would have implications for potential efficiency improvement. If it were determined that adverse events were major contributors, this would have implications for quality of care. Future work will aim to differentiate these important sources of variation in LoS among ICUs.

To date, there has been limited work to develop general models of LoS for paediatric ICU admissions. A previous risk-adjustment model for LoS in the paediatric ICU [13] was built on the Paediatric Risk of Mortality (PRISM) score as an indicator of severity of illness. This approach was consistent with models developed in the adult ICU setting which have used the APACHE score as an indicator of severity of illness[27-29]. The difficulty with such approaches is that they rely on the collection of a large number of physiological measures used for the calculation of the illness severity score[30] which are often not routinely taken.

While our model was able to estimate LoS variation among ICUs, there were several limitations. Our model was not intended to be a prognostic model for individual patients, rather it was designed to provide accurate estimates of variation among ICUs. Also, it was possible that systolic blood pressure (SBP; one of the covariates) was not missing randomly, as patients considered likely to have normal measurements may have been less likely to have SBP routinely measured. However, given SBP was missing in only 7% of cases this is unlikely to have had a significant impact.
CONCLUSION

There was significant variation in patient LoS at the ICU level not accounted for by patient case-mix. Longer LoS than predicted at a given site may be due to factors including unexplained variation in case-mix, differences in clinical practice, availability of step-down facilities or increased occurrence of adverse events such as infection.

Acknowledgements.

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Competing Interests

None of the authors had any competing interests

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REFERENCES


Figure Captions

Figure 1. Distribution of observed and predicted length of stay (truncated at 14 days) using a mixed-effects gamma regression model of paediatric admissions data from intensive care units in Australia and New Zealand, 1997-2006.
Figure 2. Box Plot showing distributions of observed and predicted length of stay for paediatric admissions in Australia and New Zealand, 1997-2006,
Figure 3. Site-specific random effect, indicating intensive care unit variation in risk-adjusted length of stay of paediatric patients in Australia and New Zealand, 1997-2006.