PICU Length of Stay: Factors Associated With Bed Utilization and Development of a Benchmarking Model

Murray M. Pollack, MD[1]; Richard Holubkov, PhD[2]; Ron Reeder, PhD[2]; J. Michael Dean, MD[2]; Kathleen L. Meert, MD[2]; Robert A. Berg, MD[3]; Christopher J. L. Newth, MD, FRCPC[4]; John T. Berger, MD[5]; Rick E. Harrison, MD[6]; Joseph Carcillo, MD[7]; Heidi Dalton, MD[8]; David L. Wessel, MD[9]; Tammara L. Jenkins, MSN, RN[6]; Robert Tamburro, MD, MSc[10]; for the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development Collaborative Pediatric Critical Care Research Network (CPCCRN)

[1]Department of Pediatrics, Children's National Health System and the George Washington University School of Medicine and Health Sciences, Washington, DC.

[2]Department of Pediatrics, University of Utah School of Medicine, Salt Lake City, UT.

[3]Department of Pediatrics, Children's Hospital of Michigan, Detroit, MI.

[4]Department of Pediatrics, Children's Hospital of Philadelphia, Philadelphia, PA.

[5]Department of Anesthesiology and Critical Care Medicine, Children's Hospital Los Angeles, University of Southern California Keck School of Medicine, Los Angeles, CA.

[6]Department of Pediatrics, Children's National Medical Center, Washington, DC.

[7]Department of Pediatrics, University of California at Los Angeles, Los Angeles, CA.

[8]Department of Critical Care Medicine, Children's Hospital of Pittsburgh, Pittsburgh, PA.

[9]Department of Child Health, Phoenix Children's Hospital and University of Arizona College of Medicine-Phoenix, Phoenix, AZ.

[10]Pediatric Trauma and Critical Illness Branch, *Eunice Kennedy Shriver* National Institute of Child Health and Human Development (NICHD), the National Institutes of Health (NIH), Bethesda, MD.

Dr. Dalton is currently affiliated with INOVA Fairfax Medical Center and George Washington University, Washington, DC.

This content is solely the responsibility of the authors and does not necessarily represent the views of the National Institutes of Health.

Dr. Pollack participated in conceptualization, design, data acquisition, and data analysis. Drs. Holubkov, Reeder, and Dean participated in conceptualization, design, and data analysis. Drs. Meert, Berg, Newth, Berger, Harrison, Carcillo, Dalton, and Wessel participated in conceptualization, design, and data acquisition. Ms. Jenkins participated in conceptualization and design. Dr. Tamburro participated in data analysis. All authors participated in data interpretation and drafting/revision. All authors have given final approval and have agreed to be accountable for all aspects of the work.

DOI: 10.1097/PCC.0000000000001425

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's website (http://journals.lww.com/pccmjournal).

Supported, in part, by the following cooperative agreements from the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development, National Institutes of Health, Department of Health and Human Services: U10HD050096, U10HD049981, U10HD049983, U10HD050012, U10HD063108, U10HD063106, U10HD063114 and U01HD049934.

All authors received support for article research from the National Institutes of Health (NIH). Drs. Pollack, Dean, Meert, Newth, Berger, Harrison, and Wessel's institutions received funding from the NIH. Drs. Holubkov, Reeder, Berg, Carcillo, and Dalton's institutions received funding from the National Institute of Child Health and Human Development. Dr. Holubkov received funding from DSMB memberships for Pfizer, Medimmune, and Armaron, and he disclosed that he was a biostatistical consultant for St Jude Medical (past), is on the Physicians Committee for Responsible Medicine (current), and was a Data Safety and Monitoring Board Member for American Burn Association (past). Dr. Newth received funding from Philips Research North America. Dr. Dalton received funding from Innovate ECMO Concepts Inc.(consultant) and Maquet Speakers Bureau. Drs. Jenkins and Tamburro disclosed government work. Dr. Jenkins disclosed that she completed this article as a federal employee at the NIH. Dr. Tamburro's institution received funding from Ony, Inc. and the U.S. Food and Drug Administration Office of Orphan Product Development, and he received funding from Springer Publishing.

For information regarding this article, E-mail: mpollack@childrensnational.org

Objectives: ICU length of stay is an important measure of resource use and economic performance. Our primary aims were to characterize the utilization of PICU beds and to develop a new model for PICU length of stay.

Design: Prospective cohort. The main outcomes were factors associated with PICU length of stay and the performance of a regression model for length of stay.

Setting: Eight PICUs.

Patients: Randomly selected patients (newborn to 18 yr) from eight PICUs were enrolled from December 4, 2011, to April 7,

2013. Data consisted of descriptive, diagnostic, physiologic, and therapeutic information.

Interventions: None.

Measurements and Main Results: The mean length of stay for was 5.0 days (SD, 11.1), with a median of 2.0 days. The 50.6% of patients with length of stay less than 2 days consumed only 11.1% of the days of care, whereas the 19.6% of patients with length of stay 4.9–19 days and the 4.6% with length of stay greater than or equal to 19 days consumed 35.7% and 37.6% of the days of care, respectively. Longer length of stay was observed in younger children, those with cardiorespiratory disease, postintervention cardiac patients, and those who were sicker assessed by Pediatric Risk of Mortality scores receiving more intensive therapies. Patients in the cardiac ICU stayed longer than those in the medical ICU. The length of stay model using descriptive, diagnostic, severity, and therapeutic factors performed well (patient-level R-squared of 0.42 and institution-level R-squared of 0.76). Standardized (observed divided by expected) length of stay ratios at the individual sites ranged from 0.87 to 1.09.

Conclusions: PICU bed utilization was dominated by a minority of patients. The 5% of patients staying the longest used almost 40% of the bed days. The multivariate length of stay model used descriptive, diagnostic, therapeutic, and severity factors and has potential applicability for internal and external benchmarking. (*Pediatr Crit Care Med* 2018; 19:196–203)

Key Words: critical care; healthcare economics; length of stay; outcomes research; pediatric critical care

Critical care efficiency and quality are associated with length of stay (LOS) (1, 2). ICUs are a major driver of hospital costs. In 2011, almost 27% of hospital stays involved ICU charges, and the hospital stays that involved the ICU were 2.5 times more costly than other hospital stays (3). The national trend in managing healthcare costs places a priority on efficient bed utilization. Operational efforts to control LOS include critical pathways, case management, and new management systems (4, 5). Managing critical care resources is often difficult because there are complex associations between personnel and facility needs when the provision of timely and sophisticated but unanticipated care by skilled personnel results in important outcome differences (6, 7).

ICU LOS is an important measure of resource use and economic performance (8, 9). Yet, ICU LOS varies with respect to many factors including severity of illness, diagnostic diversity, and other patient factors (8–11). In additional, institutional practices substantially contribute to variability as evidenced by the wide disparity in LOS for both PICU and adult ICU despite controlling for patient factors (2, 8, 9, 12, 13).

Models predicting ICU LOS have been disappointing (8, 14–16). Patient descriptive factors along with physiologic profiles are statistically important but insufficient to explain the majority of LOS variability. Most models have included therapies, and even then, model performances have been modest. For example, the proportion of variance (R^2) accounted for by an adult model using physiologic profiles, patient admission characteristics, and therapies implemented in the first 24 hours in over 200,000 patients was less than 25% (8).

There has not been a recent characterization of PICU utilization described by LOS distributions and the patient characteristics associated with resource use. Our primary aims for this analysis were to characterize the utilization of PICU beds using the focus of LOS and to develop a multivariate model for PICU LOS to better understand the importance of patient and therapeutic factors in a sample of over 10,000 patients from eight institutions. Since model performance has been disappointing using variables only from the early ICU time period, we included therapies used during the entire PICU stay and PICU outcome. Inclusion of these postadmission factors is appropriate for our goal of investigating the relationship of patient and therapeutic factors in a multivariate model with potential applicability to internal and external benchmarking.

PATIENTS AND METHODS

The data for this analysis originated in the Trichotomous Outcome Prediction in Critical Care study conducted by the Collaborative Pediatric Critical Care Research Network of the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development. Data collection methods and institutional characteristics have been previously described (17). There were seven funded sites, one being composed of two institutions. In brief, patients from newborn to less than 18 years old were randomly selected and stratified by hospital from December 4, 2011, to April 7, 2013. All sites had general medical/surgical ICUs, and six had cardiac ICUs. Patients from both general/medical and cardiac/cardiovascular PICUs were included. Moribund patients (vital signs incompatible with life for the first 2 hr after PICU admission) were excluded. Only the first PICU admission during a hospitalization was included. The protocol was approved by all participating Institutional Review Boards. Other analyses using this database have been published (17–20).

Data included descriptive and demographic information (**Supplemental Table 1**, Supplemental Digital Content 1, http://links.lww.com/PCC/A586). LOS was recorded in hours and converted to days of care starting with the first vital sign and ending with the last vital sign, with LOS less than 1 hour rounded up to 1 hour. The primary analyses treat days of care as a continuous outcome (e.g., a patient in the PICU for exactly 27 hr is analyzed as having 1.125 d of care). For display in histogram form, LOS is presented as the number of 24-hour periods in the PICU (< 1 d ≤ 24 hr, 1 d = 24 to < 48 hr, etc.) For model building (below), LOS was truncated at less than or equal to 30 days to eliminate the effects of outliers and to be consistent with other publications (8, 15, 16, 21); overall, 97.7% of patients had an actual LOS of 30 days or less. In some institutions, infants were admitted prior to cardiovascular interventions to "optimize" their preoperative status. For these infants, we used their time of admission following the operation as the initiation of intensive care stay. This a priori objective classification scheme has been published (17).

Interventions included both surgery and interventional catheterization. Diagnosis was classified by system of primary dysfunction based on the reason for PICU admission; cardiovascular conditions were classified as congenital or acquired. Cardiac arrest included closed chest massage within 24 hours prior to hospitalization or after hospital admission but prior to PICU admission. Severity of illness was characterized by physiologic profiles using the Pediatric Risk of Mortality (PRISM) score based on the first 4 hours of PICU care (22). Outcomes used in this analysis were hospital survival and death. The Functional Status Scale (FSS) was used to describe baseline (preillness) and hospital discharge functional status as good/mild dysfunction (FSS, 6 – 9) and moderate to very severe dysfunction (FSS > 9) (23). New functional status morbidity was defined as a change of FSS from baseline to hospital discharge of greater than or equal to 3 (20). Therapies included mechanical ventilation, vasoactive agents, neuromuscular blockage, antibiotics, steroids, renal replacement therapies, and extracorporeal membrane oxygenation (ECMO).

Statistical analyses used SAS 9.4 (SAS Institute Inc., Cary, NC) for descriptive statistics, model development, and fit assessment. The statistical analysis was conducted under the direction of an investigator (R.H.). Patient characteristics were evaluated for univariate association with LOS using nonparametric approaches (Kruskal-Wallis test for binary or unordered categorical variables, and Jonckeheere-Terpstra test for ordered categorical variables; continuous factors were categorized into a modest number of clinically relevant levels for these assessments.).

The final model was constructed using a nonautomated (examined by biostatistician and clinician at each step) forward stepwise selection approach from the factors significantly associated with truncated, untransformed LOS in the univariate analyses. Survival or death at PICU discharge was included as a predictor. Several categorizations of age and baseline FSS were considered in the model, as was an alternative diagnostic categorization predictive of mortality in a previous report (22). The reported model includes variables, as described above, entered sequentially with an F-statistic of significance less than 0.05 at each step; this model also achieved optimal cross-validated performance in the sequence of candidate models as assessed by the predicted residual sum of squares criterion (24).

Modifications of the above specific selection criteria, which were examined to assess robustness of the analyses, sometimes generated slightly different "final" models with very similar performances. We considered modeling log-transformed LOS as outcome, as well as using generalized linear models, and found that the predictive ability of these models for the original LOS outcome ranged from somewhat worse to only slightly better than standard regression on truncated LOS. Others have reported similar results (15). We therefore report results of the standard regression model, in part because unlike for other approaches, untransformed linear regression coefficients are directly interpretable as magnitude of change in LOS attributable to differences in a factor. Use of this untransformed model, whose residuals are not normally distributed, is acceptable for our aim of gauging whether mean PICU LOS appears to be higher or lower than expected at an aggregate, institution-wide level in this large dataset (25). SEs and significance tests reported for our model use heteroscedasticity-consistent covariance estimates robust to residual nonnormality (26).

RESULTS

Overall, the 10,078 patients stayed in the PICU for a total of 50,621 days. Supplemental Table 1 (Supplemental Digital Content 1, http://links.lww.com/PCC/A586) shows the distribution of the patient characteristics. In the total sample, 27.7% of patients were less than 1 year old. Most patients had good preillness functional status (78.6%), were emergency admissions (63.6%), and were medical patients not receiving a surgical or catheterization intervention (62.3%), and the most common primary systems of dysfunction were cardiorespiratory (57.6%) and neurologic (20.1%). ICU therapies ranged from

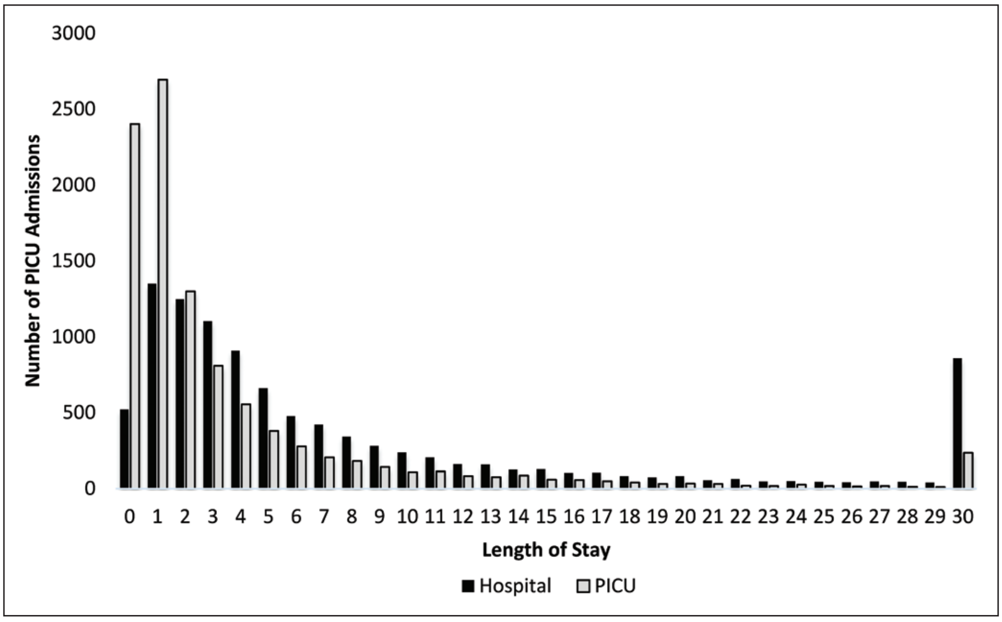

Figure 1. PICU and hospital length of stay distributions. PICU lengths of stay are skewed to short stays compared with hospital stays.

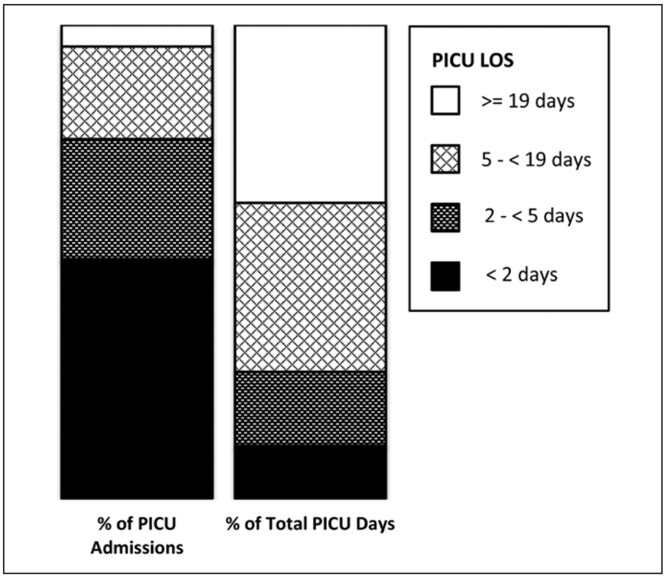

Figure 2. Utilization of PICUs by percent of admissions and percent of total PICU days. Four ranges are displayed for approximately the shortest 50%, next 25%, next 20%, and longest 5% length of stay (LOS) admissions. The corresponding percentage of days of PICU care used by these groups are indicated by identical fill patterns. Half of the study population (50.6%) with the shortest PICU LOS (< 2 d) consumed only 11.1% of the days of care. In contrast, the 19.6% of patients with LOS 4.9–19 d and the 4.6% with LOS of 19 d or longer consumed 35.7% and 37.6% of the days of care respectively.

common to very uncommon including mechanical ventilation (38.1%), vasoactive agent infusions (23.7%), neuromuscular blockade (13.6%), and ECMO (1.1%). Most patients were cared for in medical-surgical ICUs (80.8%), whereas 19.2% were cared for in cardiac ICUs. A total of 53.8% of patients had government insurance. Outcomes included death (2.7%), new significant functional status morbidity (4.6%), and intact survival (92.7%).

The mean LOS for all patients was 5.0 days (SD, 11.1), with a median length of 2.0 days. A total of 9,842 patients (97.7%) had PICU stays of 30 days or less. Truncating LOS to a maximum of 30 days accounted for 43,918 PICU days (86.8% of the days of care); the truncated LOS variable had a mean of 4.4 days (SD, 6.1), and median of 2.0 days. **Figure 1** illustrates the distributions of PICU LOS as well as LOS in the hospital. Of note, 50.6% of patients stayed in the PICU for less than 48 hours. **Figure 2** illustrates that a large number of PICU days of care are used by a relatively small proportion of the population. For example, the 50.6% of patient with LOS fewer than 2 days consumed only 11.1% of the days of care, whereas the 19.6% with LOS 4.9–19 days and the 4.6% with LOS of 19 days or longer consumed 35.7% and 37.6% of the days of care, respectively.

Supplemental Table 1 (Supplemental Digital Content 1, http://links.lww.com/PCC/A586) reports the mean and median LOS data by descriptive category, primary system of dysfunction, functional status at admission, severity of illness categories, for selected critical care therapies, and for hospital outcome. Overall, there were significant LOS differences in all patient categories except elective/emergency admission status. In general, longer LOS was observed in younger children, those with cardiorespiratory disease, postintervention cardiac patients, patients who had a cardiac arrest prior to admission, those with the highest severity of illness, and those receiving the most intensive therapies. Patients in the cardiac ICU stayed longer than those in the medical ICU (median, 3.2 vs 1.8; $p < 0.001$), and patients discharged from the hospital with a new significant functional morbidity stayed longer than deaths or those discharged without a new significant functional status morbidity. As the PRISM score increased, median LOS increased in parallel with mortality risk until a PRISM score of 20–25 when median LOS decreased due to earlier mortality (**Fig. 3**).

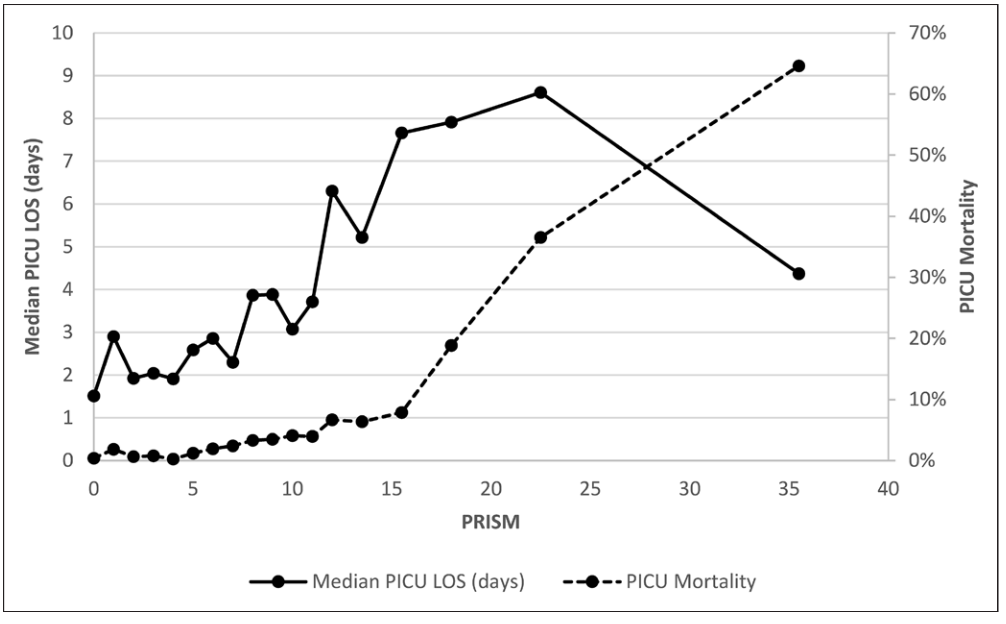

Figure 3. Length of stay (LOS) and mortality risk versus severity of illness (Pediatric Risk of Mortality [PRISM]). The median PICU LOS (*solid line*) and PICU mortality (*hashed line*) are plotted relative to the PRISM score. As the PRISM score increases, the median LOS increases in parallel with mortality risk until a PRISM score of 20–25 when median LOS decreases due to increasing deaths.

Table 1 reports the final model for LOS truncated at 30 days from data obtained during the entire PICU stay (Methods). All significant variables from Supplemental Table 1 (Supplemental Digital Content 1, http://links.lww.com/PCC/A586) were included except race which was missing in greater than 20% of patients and cardiac versus noncardiac ICU type whose association was largely subsumed by diagnosis. Age,

TABLE 1. Final Linear Regression Model for PICU Length of Stay[a]

Predictors	Coefficient (SE[c])	p for Predictor (F Test[c])
Intercept	1.28 (0.25)	< 0.001
Age at PICU admission		< 0.001
0 d to < 14 d	3.03 (0.35)	
14 d to < 1 mo	2.39 (0.57)	
1 mo to < 12 mo	0.91 (0.13)	
> 12 mo	Reference	
Admission source		< 0.001
OR/PACU for postintervention care after cardiac surgery	–3.08 (0.24)	
OR/PACU for postintervention care after noncardiac surgery	–0.57 (0.10)	
Nonpostintervention admission	Reference	
Primary system of dysfunction		0.001
Cancer	Reference	
Cardiovascular/respiratory	–0.59 (0.24)	
Low risk (endocrine, hematologic, musculoskeletal, renal)	–0.95 (0.26)	
Neurologic	–0.74 (0.25)	
Other	–0.48 (0.28)	
Baseline Functional Status Scale score categorized as moderate or severe[b]	1.28 (0.15)	< 0.001
Pediatric Risk of Mortality III total score	0.06 (0.02)	< 0.001
Died in PICU (vs discharged alive)	–3.66 (0.71)	< 0.001
Extracorporeal membrane oxygenation during PICU stay (vs no)	7.15 (0.93)	< 0.001
Renal replacement therapy during PICU stay (vs no)	2.53 (0.67)	< 0.001
Mechanical ventilation during PICU stay (vs no)	2.09 (0.13)	< 0.001
Vasoactive infusions during PICU stay (vs no)	3.27 (0.21)	< 0.001
Antibiotics during PICU stay (vs no)	1.27 (0.09)	< 0.001
Neuromuscular blockade during PICU stay (vs no)	4.79 (0.27)	< 0.001
Steroids during PICU stay (vs no)	0.97 (0.12)	< 0.001

OR = operating room, PACU = postanesthesia care unit.
[a]Length of stay in the model was truncated to a minimum of 1 hr and a maximum of 30 d.
[b]Baseline (preillness) Functional Status Scale score > 9.
[c]Coefficient SE estimates and F tests were calculated using the heteroscedasticity-consistent approach of White as noted in text.
The model R-squared was 0.42.

admission source, system of primary dysfunction, baseline functional status (dichotomized as normal/mild dysfunction vs worse), PRISM score, survival/death at PICU discharge, and the critical care therapies were included as predictors of LOS in the final regression model. The patient-level R-squared for LOS truncated at 30 days is 0.42, and the institution-level R-squared is 0.76, indicating that this model predicts truncated LOS moderately well overall (15). Notably, the model relies on therapies received during the PICU stay for a large amount of its performance. During model construction, the first four variables entered were therapies (neuromuscular blockade, vasoactive infusions, mechanical ventilation, and ECMO), and a model with these four therapies alone achieves an R-squared of 0.365. Modeling using only patient factors at admission and the admission PRISM score lead to substantially lower R-squared values around 0.16. Overall, the model generally overpredicted for short stays and underpredicted for longer stays (**Fig. 4**).

Figure 5 illustrates the LOS observed and predicted by the model when it is applied to all patients at each of the sites. The overall results are summarized as the standardized ratio of observed divided by predicted LOS (SLOSR). Among the sites, the overall SLOSR ranged from 0.87 to 1.09. There are some centers (A, D) where mean

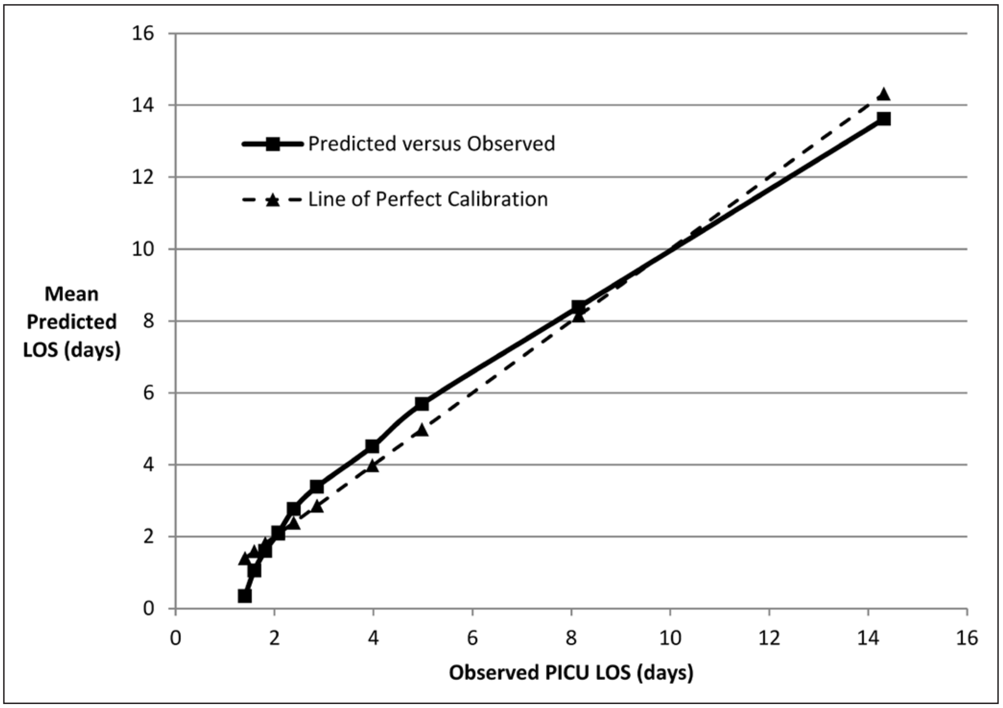

Figure 4. Mean observed versus predicted length of stay (LOS). Data are displayed by deciles of predicted LOS.

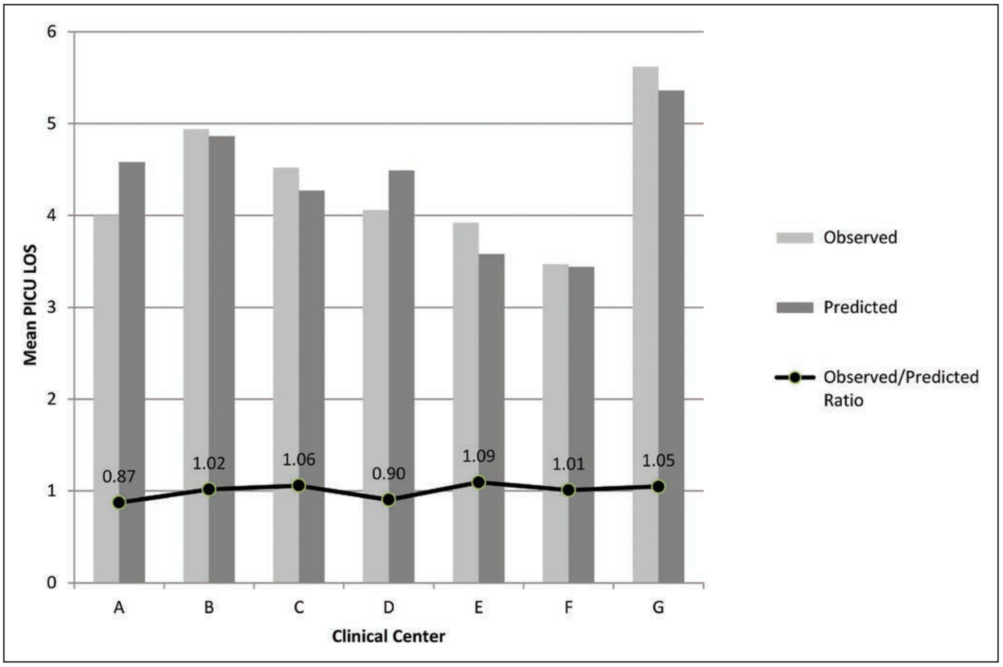

Figure 5. Observed and predicted length of stay (LOS) at the participating centers. The standardized LOS ratio is the observed divided by the expected LOS.

truncated LOS is over predicted by 0.4–0.6 days, and others (C, E, G) where mean LOS is underpredicted. These observed differences in model fit by center are statistically significant ($p < 0.0001$ by F test) when center is added as a predictor to the model in Table 1.

DISCUSSION

The efficient utilization of critical care services has important practical implications. Inefficient use of critical care beds, if it limits bed or staff availability, may result in delays in care, patient care in suboptimal care areas, or patients diverted to other facilities with the associated risks of transport and delayed therapies. Reliable methods that assess institutional bed utilization could prevent or ameliorate these suboptimal care issues if they improve efficiency and could improve the economics of critical care units (27).

We assessed PICU bed utilization in over 10,000 patients using over 50,000 days of PICU care. In this large dataset, LOS was significantly associated with essentially all patient characteristics. It displayed a known association with physiologic status where LOS increases with physiologic instability until patient deaths decreases the LOS (9, 21). Notably, although most patients stayed a relatively short time, bed utilization was dominated by a minority of patients. The 5% of patients staying the longest used almost 40% of the bed days. The patients with the highest 25% LOS used approximately 75% of the PICU bed days.

Our regression model for LOS (Table 1) used patient factors, severity of illness, outcome, and seven therapies as predictors. For the outcome LOS truncated at 30 days, the model patient-level R-squared of 0.42 and institution-level R-squared of 0.76 indicates reasonable model performance and compares favorably with other LOS models. Our model's performance is comparable with that reported in a Finnish study in adult ICUs that also used ICU survival and treatment intensity throughout the ICU stay as independent variables (13). The three factors with the largest influence in long ICU stay were therapies including ECMO, neuromuscular blockade, and vasoactive infusions. These therapies are associated with severe but often treatable cardiopulmonary disease and the need for sophisticated life support methods. Notably, when therapies were included in the modeling, they became the dominant factors with only four therapies (neuromuscular blockade, vasoactive infusions, mechanical ventilation, and ECMO) achieving an R-squared of 0.365. However, the importance of therapeutic variables emphasizes the potential issue of local therapeutic practices. Institutions that favor the use of therapies associated with longer LOS for less sick patients may appear to have better comparative performance. Using the model for internal benchmarking will ameliorate this issue.

The factor with the greatest influence on reducing LOS was death. Physiologic status (PRISM) was a significant but relatively weak factor in this model, probably because other measures of severity of illness such as therapies and outcome were included in the model. Overall, the model worked well with SLOSR ranging from 0.89 to 1.09. The model performance indicates its potential widespread applicability for internal and external benchmarking.

Comparison of critical care outcomes has been unsatisfactory when the outcomes have not been adjusted for patient characteristics unless these characteristics remain constant, an uncommon event even in single units. Therefore, statistical models generating benchmarks that are case-mix or risk adjusted are important in assessing comparative performance. In pediatrics, this has been successful for one critical care outcome, mortality (22), and has been suggested for another outcome, morbidity (17). However, these approaches have had limited success in assessing LOS (9). To improve model performance to a level that has applicability to individual units, we made several important decisions. First, we truncated the LOS data to 30 days or less to eliminate outliers. This included 97.7% of the patients but only 86.8% of the days of care. Exclusion of outliers has been a common decision in benchmarking and is consistent with federal programs that have special reimbursement structures for outliers (28). Second, we elected to include information from the entire ICU stay to improve model performance. Although this decision did result in improved model performance, it also limits the model to internal and external benchmarking as it eliminates real-time management of ICU resources. Use in real-time ICU management may require a new analytic method or a different conceptual approach (29).

Our model was primarily designed for assessing LOS for at least modestly large institution-wide cohorts. Although the model's overall performance is equivalent or better than previous efforts, its performance will not be as good in subgroups, especially those with longer LOS, and we do not recommend it for evaluation of individual patients. Deviations from predicted may be controlled by factors beyond the ICU control such as bed availability or institutional practice patterns. Despite these issues, we believe that our model has potential utility in assessing LOS utilization for PICUs and their institutions.

Institutional factors not assessed in our study are a likely cause of much of the interinstitutional variability in LOS and the limitations of statistical models predicting LOS. Institutional practice patterns and factors such as the ability of institutions to care for patients in less intense environments, nurse:patient ratios, practice patterns of physician groups, the availability of intermediate care, open versus closed units, clinical protocols and pathways, end-of-life practices, as well as other factors will significantly influence when and for how long patients are cared for in ICUs as well as the performance of statistical models (30). Additionally, the data used for these models are now approximately 5 years old, and changes in institutional resources and practices may have occurred. Models may need to be limited to internal benchmarking due to interinstitutional variability.

The length of hospital stay for pediatric patients has been relatively constant over the last 3 decades even though the average national hospital LOS has been reduced by almost 50% (31). Reductions in LOS for adults have been most marked in patients over 65 years (31). Our challenge in pediatrics will be to participate in these needed national efforts to improve efficiency and utilization while maintaining and improving quality of care. Improvements in efficiency may be aided using LOS models such as the one proposed.

CONCLUSIONS

PICU bed utilization was dominated by a minority of patients. The 5% of patients staying the longest used almost 40% of the bed days. Longer LOS was observed in younger children, those with cardiorespiratory disease, postintervention cardiac patients, and those who were sicker receiving more intensive therapies. Patients in the cardiac ICU stayed longer than those in the medical ICU. The multivariate LOS model used descriptive, diagnostic, therapeutic, and severity factors and has potential applicability for internal and external benchmarking.

ACKNOWLEDGMENTS

The members of *Eunice Kennedy Shriver* National Institute of Child Health and Human Development Collaborative Pediatric Critical Care Research Network (CPCCRN) are as follows: Teresa Liu, MPH, CCRP, University of Utah (project management, Data Coordinating Center); Jean Reardon, MA, BSN, RN, Children's National Medical Center (institutional project management, data collection); Elyse Tomanio, BSN, RN, Children's National Medical Center (institutional project management, data collection); Morella Menicucci, MD, CCRP, Children's National Medical Center (data collection); Fidel Ramos, BA, Children's National Medical Center (institutional project management, data collection); Aimee Labell, MS, RN, Phoenix Children's Hospital (institutional project management, data collection); Courtney Bliss, BS, DTR, Phoenix Children's Hospital (data collection); Jeffrey Terry, MBA, Children's Hospital Los Angeles (data collection); Margaret Villa, RN, Children's Hospital Los Angeles and Mattel Children's Hospital UCLA (institutional project management, data collection); Jeni Kwok, JD, Children's Hospital Los Angeles and Mattel Children's Hospital (institutional project management, data collection); Amy Yamakawa, BS, Children's Hospital Los Angeles and Mattel Children's Hospital UCLA (data collection); Ann Pawluszka, BSN, RN, Children's Hospital of

Michigan (institutional project management); Symone Coleman, BS, MPH; Children's Hospital of Michigan (data collection); Melanie Lulic, BS, Children's Hospital of Michigan (data collection); Mary Ann DiLiberto, BS, RN, CCRC, Children's Hospital of Philadelphia (institutional project management, data collection); Carolann Twelves, BSN, RN, Children's Hospital of Philadelphia (data collection); Monica S. Weber, RN, BSN, CCRP, University of Michigan (institutional project management, data collection); Thomas Shanley, MD, Department of Pediatrics, University of Michigan, Ann Arbor, MI; Lauren Conlin, BSN, RN, CCRP, University of Michigan (data collection); Alan C. Abraham, BA, CCRC Children's Hospital of Pittsburgh of University of Pittsburgh Medical Center (institutional project management, data collection); Jennifer Jones, RN, Children's Hospital of Pittsburgh of University of Pittsburgh Medical Center (data collection); Jeri Burr, MS, RN-BC, CCRC, University of Utah (project management, Data Coordinating Center); Nichol Nunn, BS, MBA, University of Utah (project management, Data Coordinating Center); Alecia Peterson, BS, CMC, University of Utah (project management, Data Coordinating Center); and Carol Nicholson, MD (former Project Officer, *Eunice Kennedy Shriver* National Institute of Child Health and Human Development, National Institutes of Health, Department of Health and Human Services, for part of the study period).

REFERENCES

1. Breslow MJ, Badawi O: Severity scoring in the critically ill: Part 2: Maximizing value from outcome prediction scoring systems. *Chest* 2012; 141:518–527
2. Gemke RJ, Bonsel GJ: Comparative assessment of pediatric intensive care: A national multicenter study. Pediatric Intensive Care Assessment of Outcome (PICASSO) Study Group. *Crit Care Med* 1995; 23:238–245
3. Barrett ML, Smith MW, Elixhauser A, et al: Utilization of Intensive Care Services, 2011. Statistical Brief #185. Rockville, MD, Agency for Healthcare Research and Quality, 2014
4. Ahmed S, Manaf NH, Islam R: Effects of Lean Six Sigma application in healthcare services: A literature review. *Rev Environ Health* 2013; 28:189–194
5. Zander K: A 30-year retrospective: Degrees of difficulty in decreasing LOS. *Prof Case Manag* 2016; 21:233–242
6. Pollack MM, Alexander SR, Clarke N, et al: Improved outcomes from tertiary center pediatric intensive care: A statewide comparison of tertiary and nontertiary care facilities. *Crit Care Med* 1991; 19:150–159
7. Pollack MM, Cuerdon TT, Patel KM, et al: Impact of quality-of-care factors on pediatric intensive care unit mortality. *JAMA* 1994; 272:941–946
8. Kramer AA, Zimmerman JE: The relationship between hospital and intensive care unit length of stay. *Crit Care Med* 2011; 39:1015–1022
9. Ruttimann UE, Patel KM, Pollack MM: Length of stay and efficiency in pediatric intensive care units. *J Pediatr* 1998; 133:79–85
10. Ruttimann UE, Pollack MM: Variability in duration of stay in pediatric intensive care units: A multiinstitutional study. *J Pediatr* 1996; 128:35–44
11. Ruttimann UE, Patel KM, Pollack MM: Relevance of diagnostic diversity and patient volumes for quality and length of stay in pediatric intensive care units. *Pediatr Crit Care Med* 2000; 1:133–139
12. Straney L, Clements A, Alexander J, et al; ANZICS Paediatric Study Group: Quantifying variation of paediatric length of stay among intensive care units in Australia and New Zealand. *Qual Saf Health Care* 2010; 19:e5
13. Niskanen M, Reinikainen M, Pettilä V: Case-mix-adjusted length of stay and mortality in 23 Finnish ICUs. *Intensive Care Med* 2009; 35:1060–1067
14. Suistomaa M, Niskanen M, Kari A, et al: Customized prediction models based on APACHE II and SAPS II scores in patients with prolonged length of stay in the ICU. *Intensive Care Med* 2002; 28:479–485
15. Verburg IW, de Keizer NF, de Jonge E, et al: Comparison of regression methods for modeling intensive care length of stay. *PLoS One* 2014; 9:e109684
16. Vasilevskis EE, Kuzniewicz MW, Cason BA, et al: Mortality probability model III and simplified acute physiology score II: Assessing their value in predicting length of stay and comparison to APACHE IV. *Chest* 2009; 136:89–101
17. Pollack MM, Holubkov R, Funai T, et al; Eunice Kennedy Shriver National Institute of Child Health and Human Development Collaborative Pediatric Critical Care Research Network: Simultaneous prediction of new morbidity, mortality, and survival without new morbidity from pediatric intensive care: A new paradigm for outcomes assessment. *Crit Care Med* 2015; 43:1699–1709
18. Pollack MM, Dean JM, Butler J, et al: The ideal time interval for critical care severity-of-illness assessment. *Pediatr Crit Care Med* 2013; 14:448–453
19. Pollack MM, Holubkov R, Funai T, et al: Relationship between the functional status scale and the pediatric overall performance category and pediatric cerebral performance category scales. *JAMA Pediatr* 2014; 168:671–676
20. Pollack MM, Holubkov R, Funai T, et al; Eunice Kennedy Shriver National Institute of Child Health and Human Development Collaborative Pediatric Critical Care Research Network: Pediatric intensive care outcomes: Development of new morbidities during pediatric critical care. *Pediatr Crit Care Med* 2014; 15:821–827
21. Zimmerman JE, Kramer AA, McNair DS, et al: Intensive care unit length of stay: Benchmarking based on Acute Physiology and Chronic Health Evaluation (APACHE) IV. *Crit Care Med* 2006; 34:2517–2529
22. Pollack MM, Holubkov R, Funai T, et al. The pediatric risk of mortality score: update 2015. *Pediatr Crit Care Med* 2016; 17:2–9
23. Pollack MM, Holubkov R, Glass P, et al; Eunice Kennedy Shriver National Institute of Child Health and Human Development Collaborative Pediatric Critical Care Research Network: Functional Status Scale: New pediatric outcome measure. *Pediatrics* 2009; 124:e18–e28
24. Allen DM: The relationship between variable selection and data augmentation and a method for prediction. *Technometics* 1974; 16:125–127
25. Lumley T, Diehr P, Emerson S, et al: The importance of the normality assumption in large public health data sets. *Annu Rev Public Health* 2002; 23:151–169
26. White H: Heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. *Econometrics* 1980; 48:817–838
27. Weeks WB, Resar R: Does reducing length of stay make a business case? *Jt Comm J Qual Patient Saf* 2008; 34:627–628
28. Silberstein GS, Paulson AS: Summary of prospective quantification of reimbursement recovery from inpatient acute care outliers. *J Health Care Finance* 2011; 38:83–98
29. Levin SR, Harley ET, Fackler JC, et al: Real-time forecasting of pediatric intensive care unit length of stay using computerized provider orders. *Crit Care Med* 2012; 40:3058–3064
30. Gruenberg DA, Shelton W, Rose SL, et al: Factors influencing length of stay in the intensive care unit. *Am J Crit Care* 2006; 15:502–509
31. DeFrances CJ, Hall MJ: 2005 national hospital discharge survey. *Adv Data* 2007; 385:1–19