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Original Article

Comparison of the Pediatric Risk of Mortality Score III, Risk Adjustment for Congenital Heart Surgery 1 and Pediatric Index of Cardiac Surgical Intensive Care Mortality Score in Post-Operative Pediatric Cardiac Surgical Patients: A Single-Center Validation Study in South India

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Abstract

Background: Outcome predictions of mortality using scoring systems have now become an integral part of the intensive care units (ICUs). The present study compared and validated the pediatric risk of mortality III (PRISM-III), risk adjustment for congenital heart surgery 1 **(**RACHS-1) and pediatric index of cardiac surgical intensive care mortality (PICSIM) score for predicting mortality and ICU length of stay (ICU-LOS) in post-operative pediatric cardiac surgical patients in an Indian cohort.

Methods: The study conducted at Amrita Institute of Medical Sciences and Research Center during the period January 2020–December 2020. Total 269 patients <18 years of age undergoing congenital heart surgery and admitted into the pediatric cardiac ICU (PCICU) were included in the study. Physiologic variables collected within 1 h and 12 h of admission to PCICU after cardiac surgery were used to calculate PRISM-III and PICSIM. RACHS-1 category was assigned based on the surgical procedure performed. Correlation and regression analysis was applied to quantify and confirm the association between each categorical independent and dependent variable.

Results: There was a significant ($P < 0.001$) positive correlation between the ICU-LOS of patients and RACHS-1 score ($r = 0.553$), PRISM-III ($r = 0.418$) and PICSIM score ($r = 0.582$), PICSIM seemed to have a better correlation with ICU-LOS. The area under the curve for PRISM-III score (0.920) was slightly higher compared with PICSIM (0.813) and RACHS-1 (0.708). This result indicates that PRISM-III score showed better prediction of mortality as compared to PICSIM and RACHS-1 system.

Conclusion: The study concluded that PICSIM score demonstrated better performance in predicting ICU-LOS and next to PRISM-III in predicting mortality in an Indian cohort. All the 3 risk stratification models had significant correlation with ICU-LOS. Therefore, identifying cohorts with worsen outcomes will enable PCICUs to deliver better quality of care to vulnerable patients.

Key words: Mortality prediction, Pediatric cardiac intensive care unit, Pediatric index of mortality 3, Pediatric risk of mortality

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INTRODUCTION

In recent years due to advancements in intensive care, prenatal diagnosis, neonatal surgery, cardiac catheterization and anesthesia, and cardiopulmonary bypass techniques, there was significant improvement observed in the treatment and diagnosis of congenital heart disease

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(CHD).[1] As a result of medical advancement, the in-hospital mortality rates after pediatric heart surgery reduced appreciably from 4.3% to 2.2%.[2,3] A suitable mortality risk scoring system can accurately predict mortality while adjusting the severity of disease, and capture possible data in clinical practice.[4-6] Usual pediatric intensive care scores determine intensive care unit (ICU) admission, and the prediction data are typically obtained both before and after ICU admission. Most commonly used mortality prediction models in pediatric intensive care units are pediatric index of mortality 3 (PIM-3), and pediatric risk of mortality (PRISM-III). Pollack *et al.* in 1996 developed PRISM-III, a third generation mortality scoring system based on pediatric physiology for mortality risk assessment of infant.[7] PRISM scoring model is a physiology-based severity of illness assessment tool utilized in adult and pediatric intensive care population. This scoring system gives values reflective of mortality risk based on derangements in physiological variables. PRISM scoring model has been shown to be effective in patients undergoing congenital heart surgery. The PRISM scoring algorithm simultaneously estimates fresh functional morbidity and mortality from hospital discharge.[8-10] Prior study also compared and validated different prediction models and demonstrated advantages of one score over the other scores in terms of being fewer affected by the retrieval process and easier to assemble.[11] Recently, data from a large multicenter study has revealed that the performance of PRISM-III was suboptimal when applied to assess mortality risk specifically in pediatric cardiac surgical patients and cardiac medical populations.[10]

The risk adjustment for congenital heart surgery 1 (RACHS-1) score is capable of categorizing patients into six groups based on the type of surgical procedure to predict hospital mortality.[12-14] RACHS-1 score is extensively applied to evaluate mortality and to compare the performance of cardiac surgical units. The RACHS-1, however, does not consider the individual and structural components of services that directly influence operational outcome. However, successful integration of pediatric index of cardiac surgical intensive care mortality (PICSIM) in assessing and correcting ICU care of children undergoing heart surgery can address these challenges.[5,15] PICSIM score overlies with the PIM which does not execute well in heart surgery patients. As the majority of PICSIM's prediction capacity comes from the operational complication score, thus PICSIM score to evaluate intensive patient care quality is restricted.[16,17] Jeffries *et al.* developed a mortality risk-assessment tool exclusively for the pediatric cardiac surgical intensive care patients named as the PICSIM score which is based on common and targeted categorical variables, and a partial set of physiological and therapeutic variables. PICSIM score aimed at assessing the relationship of the ICU components to cardiac surgical care and mortality in infants undergoing congenital heart surgery.[18,19] Since the majority of PICSIM's prognostic command comes from the surgery or operational complexity score, use of PICSIM to evaluate intensive care is partial.[16,20] The prevalence of CHD is not uniform in India varying from 1.3 to 50.89/1000 live births.[21] In India, 10% of the present newborn child mortality might be accounted to CHD. Prolonged ICU stay after pediatric cardiac surgery often indicates a greater severity of illness and has been associated with poor outcomes.[22] In addition, prolongation of intensive care demands tremendous resource utilization and present substantial challenges to the viability of pediatric heart programs. Validating scoring systems which has the potential to predict ICU-length of stay (ICU-LOS) thus becomes relevant in limited-resource settings. There is a paucity of data pertaining to validation of risk prediction models in pediatric cardiac surgical patients from developing countries. At our center, we have been traditionally using the RACHS-1 scoring system for categorizing pediatric cardiac surgical patients in terms of surgical complexity and severity of illness. However, with the emergence of newer tools like PICSIM which has been acclaimed for better performance in pediatric cardiac surgical patients and a decline in mortality rates at our center to <2.5%, we sought to compare and validate the PICSIM score, PRISM-III score, and RACHS-1 score for predicting mortality and ICU-LOS in post-operative cardiac surgical patients in an Indian population. Therefore, the main objective of the present study was to compare and validate the PICSIM score, PRISM-III score, and RACHS-1 score for predicting mortality and length of ICU-LOS in post-operative pediatric cardiac surgical patients in an Indian cohort.

METHODS

Selection and Description of Participants

This is a prospective validation study conducted at Amrita Institute of Medical Sciences which is a tertiary care multispecialty hospital in South India. The study was conducted during the period January 2020–December 2020. The study was approved by the institutional review board and a written informed consent was obtained from the parents of all participants before recruitment into the study [Appendix 1: Informed consent]. Consecutive patients <18 years of age undergoing congenital heart surgery and admitted into the pediatric cardiac ICU (PCICU) for perioperative care were recruited into the study.

Since we did not come across a previous study in literature which validated the risk scoring tools in paediatric cardiac patients in an Indian cohort for sample size prediction, a pilot study was conducted with 10 patients. Based on correlation coefficient of ICU-LOS obtained with scoring systems, namely RACHS-1, PRISM-III, and PICSIM in the pilot study and with 95% confidence interval and 80% power, minimum sample size was estimated to be 198.

Technical Information

The primary objective of the study is to compare and validate the three risk stratification models, namely PRISM-III, RACHS, and PICSIM score as a predictors of ICU-LOS in post-operative pediatric cardiac intensive care patients in the Indian population.

The secondary objective is to assess mortality.

Inclusion criteria

All consecutive patients <18 years of age undergoing congenital heart surgery and admitted into the PCICU for perioperative care were included in the study.

Exclusion criteria

1. Patients above the age of 18 years undergoing congenital heart surgery
2. Patients who underwent cardiac surgery and transferred directly to neonatal ICU or intermediate care unit from the operating room were also excluded.

All patients in the study cohort were admitted into a dedicated PCICU after congenital heart surgery. Patients who were critically ill before surgery sometimes needed admission to the PCICU before surgery for preoperative optimisation and hence the time of admission to the PCICU with respect to cardiac surgery (i.e. before or after cardiac surgery) was also included among the variables. Preoperative variables, including demographic data, anthropometric measurements, and cardiac diagnosis, were collected at the time of pre-operative anesthesia evaluation. Physiological variables that were collected prospectively within 1 h and 12 h of admission to PCICU after cardiac surgery were used to calculate PRISM-III and PICSIM. RACHS-1 category and STAT scores were assigned based on the surgical procedure performed. The preoperative, intra-operative, and postoperative variables required for calculating the three risk scores are elaborated in the study pro forma which was used for the data collection [Appendix 2: The study pro forma]. The outcome variables included 30-day mortality and ICU-LOS. ICU-LOS was defined as the time interval in hours from admission to PCICU after surgery to discharge from the PCICU.

Statistics

Statistical analysis was done using IBM SPSS Statistics for Windows, version 23.0 (Armonk, NY: IBM Corp.). The categorical variables were expressed as frequencies and percentage. The continuous variables were expressed as mean ± standard deviation or median and range as appropriate. The correlation between ICU-LOS (hours) and RACHS-1, PRISM-III, and PICSIM score was analyzed using the Spearman correlation test. Linear regression was employed to find out the effect of one variable on others. The association between mortality and RACHS-1, PRISM-III and PICSIM score was calculated using regression analysis. Validation of three risk stratification models to predict mortality was performed by analysis of receiver operating characteristic (ROC) curve and area under the curve (AUC) obtained for each model. $P < 0.05$ was statistically considered to be significant.

RESULTS

269 patients were recruited in to the study, of these 153 (56.9%) were male and 116 (43.1 %) were female. The height and weight of the patients was 7.63 ± 8.49 kg and the mean height was 68.36 ± 24.71 cm. The distribution of patients according to surgical procedure shown in the [Figure 1] BAR diagram and the most frequent being ventricular septal defect (VSD) repair (22.7%), repair of tetralogy of Fallot (17.8%), and arterial switch operation with/without VSD closure (12.6%).

In this study, we observed that the minimum ICU-LOS was 20 h and maximum ICU-LOS was 1152 h. Moreover, the mortality in the entire study cohort was 1.9%.

On correlating ICU-LOS with PRISM-III, we get a positive moderate correlation coefficient (r = 0.418) which was found to be statistically significant with $P < 0.001$. This represents that, when the PRISM-III increases, the ICU-LOS will also increase. Positive changes in PRISM-III will reflect as positive changes in ICU-LOS and this holds true vice versa as well [Table 1 and Figure 2].

Regression equation with PRISM-III and ICU-LOS = 9.606 (PRISM-III) + 71.002

On correlating ICU-LOS with RACHS-1, we get a positive moderate correlation coefficient (r = 0.553) which was found to be statistically significant with $P < 0.001$. This represents that, when the RACHS-1 score increases, the ICU-LOS will also increase. Positive changes in RACHS-1 will reflect as positive changes in ICU-LOS and this holds true vice versa as well [Table 2 and Appendix 1].

Regression equation with RACHS-1 and ICU-LOS = 41.68 (RACHS-1) + 19.485

On correlating ICU-LOS with PICSIM, we get a positive moderate correlation coefficient (r = 0.582) which was found

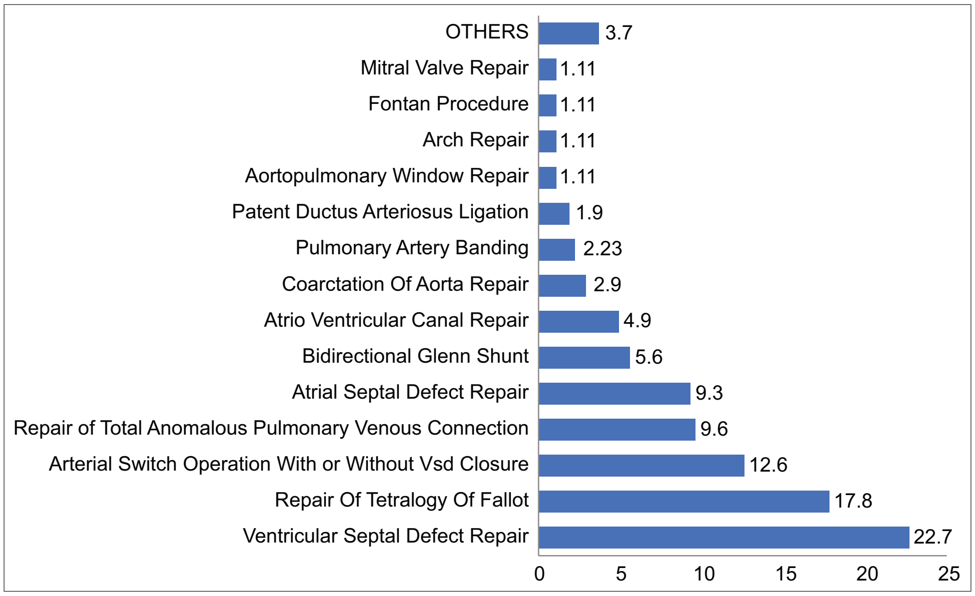

Figure 1: Bar diagram for distribution of cardiac surgical procedures

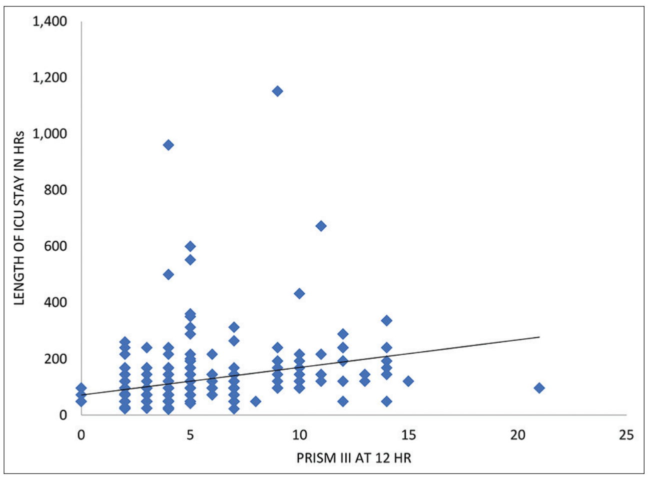

Figure 2: Scatter diagram for length of intensive care unit stay versus pediatric risk of mortality-III

Table 1: Correlation between length of ICUs stay and PRISM-III

Correlation between length of ICU stay and PRISM-III score	
Spearman's coefficient of correlation (r)	0.418
P	<0.001
n	269

ICU: Intensive care units, PRISM-III: Pediatric risk of mortality score III

to be statistically significant with $P < 0.001$. This represents that, when the PICSIM score increases, the ICU-LOS will also increase. Positive changes in PICSIM will reflect as positive changes in ICU-LOS and this holds true vice versa as well [Table 3 and Appendix 2].

Regression equation with PICSIM score and ICU-LOS= 4.965(PICSIM) + 73.401

Table 2: Correlation between length of ICUs stay and RACHS-1

Correlation between length of ICU stay and RACHS-1	
Spearman's coefficient of correlation (r)	0.553
P	<0.001
n	269

ICU: Intensive care units, RACHS-1: Risk adjustment for congenital heart surgery 1

Table 3: Correlations between length of ICUs stay and PICSIM score

Correlation between length of ICU stay and PICSIM	
Spearman's coefficient of correlation (r)	0.582
P	<0.001
n	269

ICU: Intensive care units, PICSIM: Pediatric index of cardiac surgical intensive care mortality score

Appendix 3 depicts ROC curve for RACHS-1, PRISM-III, and PICSIM score. In ROC curve, higher X-axis value indicates a higher number of false positives whereas, higher Y-axis value indicates a higher number of true positives rate. Here, PICSIM showed better true positive rate as compared to RACHS-1 and PRISM-III. Therefore, PICSIM has better discriminative power for predicting mortality as compared to RACHS-1 and PRISM-III.

The discrimination based on the AUC for PRISM-III at 12 h score (0.920) was observed to be higher compared to PICSIM (0.813) or RACHS-1 (0.708). This indicates that PRISM-III score showed slightly better prediction of mortality as compared to PICSIM and RACHS-1 system and was found to be statistically significant with $P < 0.001$ [Table 4 and Appendix 3].

DISCUSSION

The various risk stratification tools in pediatric cardiac surgical patients allow prediction of adverse outcomes and benchmarking of performance between various pediatric cardiac units. Previous studies have demonstrated that severity of illness scores such as mortality score would execute better in homogenous populations. Prediction scores developed for general paediatric critical care may not work appropriately in specific population subsets such as cardiac surgical patients.[7,8] Thus, it is important to develop and validate severity of illness scores for individual disease condition and population. Severity of illness scores has tremendous applications in low-middle income countries for triaging critically patients as well as facilitating optimal utilization of available resources. Although RACHS-1, PRISM-III, and the newly developed PICSIM scores are being currently applied to pediatric cardiac surgical patients in most of the developed nations, there is a paucity of data pertaining to the validation of these risk scoring tools in an Indian cohort. Our study has been an attempt to compare and validate the three risk stratification models namely PICSIM, RACHS-1 and PRISM-III to predict mortality and ICU-LOS in an Indian population.

The present study revealed that PRISM-III scoring system showed better prediction of mortality as compared to PICSIM and RACHS-1. The 30-day mortality rate of 1.9% observed in our study is comparable to the outcomes from the developed world.[1,3] We evaluated AUC from ROC curve to compare and validate mortality prediction systems. The discrimination based on the AUC for PRISM-III at 12 h score (0.920) was higher compared with PICSIM (0.813) and RACHS-1 (0.708). Although all risk models showed significant positive correlation with ICU-LOS, PICSIM (0.582) showed marginally better correlation compared to RACHS -1 (0.553) and PRISM–3 (0.418). The results of regression analysis also conclude that all three risk scoring models have utility in predicting the ICU-LOS.

Table 4: Area under the receiver operating curve for RACHS-1, PRISM-III and PICSIM

Variable	Area under the curve	*P*	Asymptotic 95% CI	
			Lower bound	Upper bound
RACHS-1 category score	0.708	0.244	0.358	1.058
PRISM-III at 12 h	0.920	<0.001	0.787	1.053
PICSIM score	0.813	0.003	0.609	1.018

CI: Confidence interval, PICSIM: Pediatric index of cardiac surgical intensive care mortality score, PRISM-III: Pediatric risk of mortality score III, RACHS-1: Risk adjustment for congenital heart surgery 1

Since most risk scoring systems rely on mortality and surgical complexity, the impact of ICU elements on clinical outcomes may not be accurately projected while using these models in paediatric cardiac population subsets. This often limits the applicability of mortality-based scoring systems for quality improvement in therapeutic approaches in pediatric cardiac intensive care. PICSIM score, in addition to physiological variables and STAT score also factors in supplementary data like timing of admission to ICU with respect to cardiac surgery and employment of extracorporeal life support within 12 h of post-operative ICU admission. Tibby SM *et al*. in his elegant study showed that the PICSIM had better capability to discriminate risk of mortality as compared to PRISM-III, PIM-2, and the complexity-based scores (STAT categories and RACHS-1 score) for children undergoing heart surgery.[11] The capability to discriminate risk of mortality was found excellent, both for low and high-risk cardiac surgery patients. Our results demonstrating improved performance of PICSIM in predicting ICU-LOS but PRISM-III had slight edge over PICSIM in predicting mortality according to our study as AUC of PRISM-III at 12 h (0.920). We speculate that the enhanced performance of PICSIM in predicting ICU-LOS in paediatric cardiac patients might be attributed to the addition of ICU-related variables which are not included in either RACHS-1 or in PRISM-III. In addition, PICSIM was validated exclusively in the unique subset of patients undergoing congenital heart surgery. Overall, these results indicate that the PICSIM score is more appropriate for predicting ICU-LOS and severity of illness in pediatric cardiac surgical population. Moreover, pairwise comparison of RACHS, PRISM-III at 12 h, and PICSIM was not found to be statistically significant.

We would like to highlight the fact that the present study is particularly relevant in the context of resource-limited environments for identifying those patients who are likely to have adverse outcomes and an extended stay in the post-operative period. Prolonged ICU stay can often exhaust ICU resources and challenge the economic viability of many paediatrics heart programs in the developing world. Identifying patients who are likely to overstay early in the disease trajectory can enable the caretakers to target high quality perioperative care to the vulnerable patients with the goal of improving overall survival and post-operative morbidity.

There are some limitations to this study. First, the physiological variables included in the PICSIM score offer only a marginal enhancement in the ability to discriminate ICU-LOS and slightly lesser prediction in mortality than PRISM-III as indicated by AUC (PICSIM 0.813, PRISM-III 0.92, RACHS-0.708). Therefore, capability of PICSIM to discriminate ICU-LOS and mortality is mostly influenced by surgical complexity, hence restraining its capacity to facilitate quality improvement. Second, we acknowledge the fact that the present study was conducted on a small sample size of 269 patients, and thus need further validation in larger patient populations. Third, PICSIM has not been comprehensively evaluated in cohorts of pediatric cardiac patients admitted to ICU for cardiac intensive care and not undergoing surgery in the subsequent period.

CONCLUSION

Based on the results of our study, we conclude that PICSIM score demonstrated better discriminative power in predicting ICU-LOS after congenital heart surgery compared to PRISM-III and RACHS-1 and next to PRISM-III in predicting mortality in an Indian cohort. There was significant positive correlation between all the 3 risk stratification models (PICSIM, RACHS-1 and PRISM-III) with ICU-LOS after congenital heart surgery and pairwise comparison wasn't statistically significant. Even though by a low margin, PICSIM seemed to have a better correlation with ICU-LOS in post-operative paediatric cardiac patients compared to PRISM-III and RACHS-1. Identifying cohorts who are likely to have worser outcomes will enable PCICUs to target high quality care to vulnerable patients.

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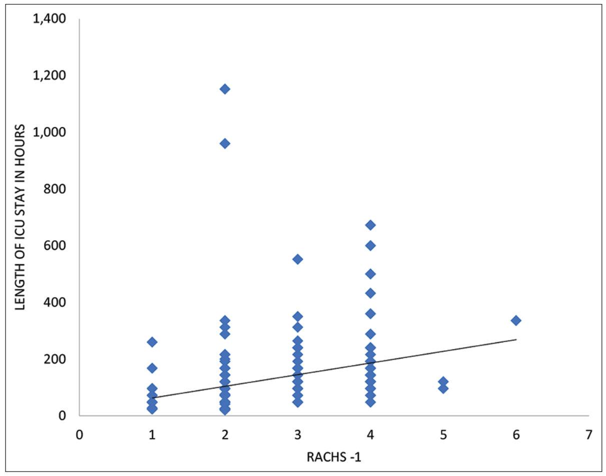
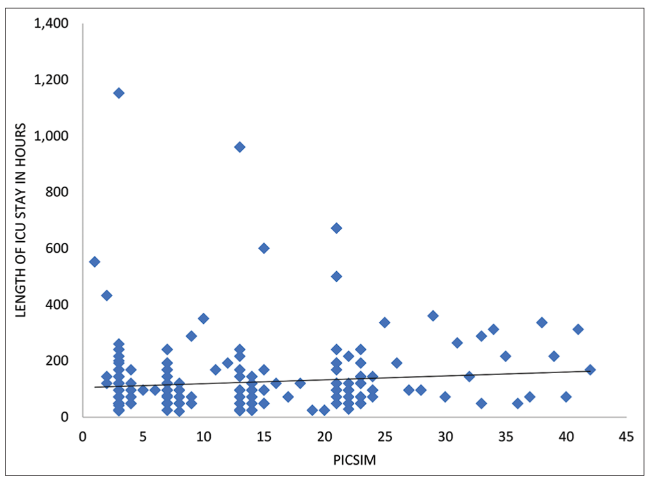
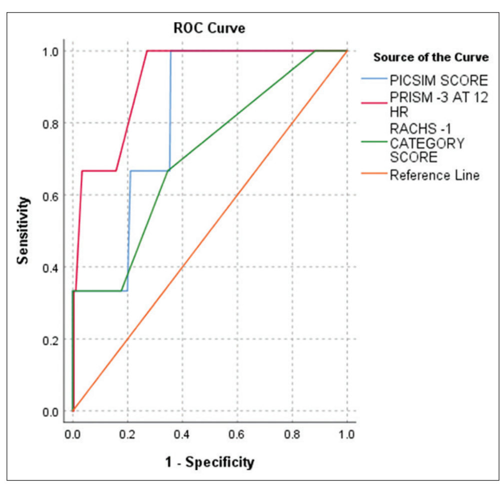
APPENDIX



Appendix 1: Scatter diagram for intensive care unit stay versus risk adjustment for congenital heart surgery-1



Appendix 2: Scatter diagram for length of intensive care unit stay and pediatric index of cardiac surgical intensive care mortality



Appendix 3: Receiver operating characteristic (ROC) curve for risk adjustment for congenital heart surgery-1, pediatric risk of mortality-III and pediatric index of cardiac surgical intensive care mortality