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sTREM-1 Concentrations in Children Undergoing Cardiac Surgery: Description of Biomarker Levels According to RACHS-1 and TISS-28 Categories

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Abstract

Congenital heart defects represent prevalent malformations requiring complex surgical interventions. Outcomes are influenced by clinical severity, inflammatory response, and complexity of care, highlighting the need for improved risk stratification tools. Objectives: To describe the behavior and distribution of perioperative sTREM-1 concentrations in a pediatric cohort undergoing cardiac surgery, exploratorily stratified by RACHS-1 and TISS-28 severity scores. Methods: A translational cross-sectional study was conducted with 32 children (aged 0–14 years) undergoing surgical correction for congenital heart disease at a Brazilian public referral hospital (2021–2022). Exclusion criteria included genetic syndromes, active infections, or previous cardiac surgeries. Clinical severity was assessed using RACHS-1 (mortality risk) and TISS-28 (care complexity) scores. Serum sTREM-1 levels were measured via ELISA preoperatively and postoperatively. Statistical analysis involved the Shapiro–Wilk normality test, descriptive statistics expressed as medians and interquartile ranges, and Spearman's rank correlation coefficient to evaluate the relationship between sTREM-1 levels and severity scores, with significance set at $p < 0.05$. Results: The cohort consisted predominantly of males (56.25%), term infants (93.75%), with 50% presenting cyanosis. RACHS-1 category 3 was most common (34.37%), while TISS-28 category 2 predominated (40.62%). Most patients were discharged (93.75%). Preoperative sTREM-1 levels showed no significant correlation with RACHS-1 ($r_s = 0.265$; $p = 0.143$) or TISS-28 scores ($r_s = 0.227$; $p = 0.212$). Conversely, postoperative sTREM-1 concentrations significantly and positively correlated with both RACHS-1 ($r_s = 0.356$; $p = 0.045$) and TISS-28 categories ($r_s = 0.394$; $p = 0.026$), reflecting higher biomarker levels in more severe clinical

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scenarios. Conclusions: Postoperative sTREM-1 levels correlated significantly with surgical risk and clinical severity, showing higher median concentrations in more severe RACHS-1 and TISS-28 categories. Conversely, no preoperative correlation was observed, suggesting sTREM-1 primarily reflects postoperative inflammatory responses and surgical complexity.

Keywords: clinical severity; biomarker; trigger receptor expressed on myeloid cells-1; TISS-28; RACHS-1

1. Introduction

Congenital heart defects (CHD) are the most prevalent congenital malformations, constituting structural and functional abnormalities with a broad clinical spectrum from asymptomatic to life-threatening conditions [1]. Globally affecting millions, CHD remains a significant cause of pediatric morbidity and mortality, with complex cases requiring early surgical intervention to improve survival outcomes [2]. These highly complex procedures carry inherent organic repercussions, with outcomes influenced by multiple factors, including patient age, comorbidities, surgical type, and postoperative complications [3,4]. Effective risk stratification is essential for optimizing care quality and patient safety throughout the treatment continuum. Clinical assessment instruments provide valuable parameters for establishing care priorities and resource allocation from admission to discharge [5]. The Therapeutic Intervention Scoring System (TISS-28) serves as a widely adopted tool for quantifying nursing care workload based on clinical severity and intervention complexity [6]. Similarly, the Risk Adjusted Congenital Heart Surgery Score-1 (RACHS-1) categorizes surgical procedures by mortality risk, enabling refined understanding of postoperative outcomes [7,8].

Complementing these validated clinical instruments, biomarker assessment offers additional prognostic stratification capabilities. Measurement of biological markers enables evaluation of normal physiological processes, pathological states, and responses to therapeutic interventions. Among these, soluble Triggering Receptor Expressed on Myeloid Cells-1 (sTREM-1) has emerged as a promising inflammatory biomarker. As a member of the immunoglobulin superfamily expressed on neutrophils, monocytes and macrophages, sTREM-1 plays a regulatory role in inflammatory signaling pathways [9]. Research has demonstrated its utility in various clinical contexts, including as a predictive tool for disease outcomes in conditions such as COVID-19 [10]. The integration of inflammatory biomarkers like sTREM-1 with established clinical scoring systems may enhance risk prediction accuracy and support more personalized treatment approaches in pediatric cardiac care, ultimately contributing to improved patient outcomes and resource optimization in critical care settings.

This study investigates the association between the inflammatory biomarker sTREM-1 and validated clinical scales (TISS-28, RACHS-1) in pediatric patients after cardiac surgery. The rationale is that surgery induces an inflammatory response and sTREM-1 expression. sTREM-1 levels were evaluated to describe how this biomarker behaves across different categories of validated scales.

2. Results

Of the 32 patients, the majority were male (56.25%), term (93.75%) and underwent elective surgery (53.12%). As for the clinical data, 50% had cyanosis, 34.37% were classified in category 3 of the RACHS-1, and 40.62% in category 2 of the TISS-28, and there was a predominance of the outcome discharge (93.75%) (Table 1).

Table 1. Distribution of sociodemographic and clinical characteristics of children undergoing cardiac surgery.

Variable	*n*	%
Gender		
Male	18	56.3
Female	14	43.7
Classification according to gestational age		
Term	30	93.8
Preterm	1	3.1
Post-term	1	3.1
Type of Surgery		
Elective	17	53.1
Emergency	15	46.9
Presence of cyanosis		
Yes	16	50.0
No	16	50.0
Preoperative Classification of Heart Disease—RACHS-1		
Category 1 (C1)	3	9.4
Category 2 (C2)	10	31.2
Category 3 (C3)	11	34.4
Category 4 (C4)	8	25.0
Classification of Postoperative Patient Severity—TISS-28		
Category 1 (C1)	0	-
Category 2 (C2)	13	40.6
Category 3 (C3)	11	34.4
Category 4 (C4)	8	25.0
Outcomes		
Discharge	30	93.7
Deaths	2	6.3
Total	32	100

The normality analysis of the data, performed using the Shapiro–Wilk test, revealed a non-parametric distribution for sTREM-1 concentrations in most of the evaluated categories ($p < 0.05$; Supplementary Table S1). For this reason, the data were expressed as medians and interquartile ranges (IQR). To evaluate the biomarker's behavior in relation to clinical severity and surgical risk without incurring the error of multiple comparisons, Spearman's ordinal correlation analysis (r_s) was used. In the preoperative period, no statistically significant correlations were observed between sTREM-1 levels and RACHS-1 (r_s = 0.265; $p = 0.143$) or TISS-28 (r_s = 0.227; $p = 0.212$) categories. In contrast, in the postoperative period, a moderate and statistically significant positive correlation was identified for both the RACHS-1 score (r_s = 0.356; $p = 0.045$) and the TISS-28 score (r_s = 0.394; $p = 0.026$), indicating that higher levels of surgical severity and complexity are associated with higher postoperative concentrations of the biomarker (Table 2).

Table 2. RACHS-1 and Tiss-28 categories and mean sTREM-1 concentrations in the pre- and postoperative period of children undergoing cardiac surgery.

Severity Scores	Preoperative Median (IQR)	Postoperative Median (IQR)	Spearman Coefficient (rs)	*p*-Value
		RACHS-1		
Category 1 ($n = 3$)	208.99 (154.65–250.42)	222.29 (212.02–232.93)		
Category 2 ($n = 10$)	164.94 (126.56–211.92)	215.65 (164.05–343.88)	Pre: 0.265	Pre: 0.143
Category 3 ($n = 11$)	152.02 (111.04–185.39)	220.79 (177.76–326.44)	Post: 0.356	Post: **0.045**
Category 4 ($n = 8$)	238.39 (161.97–273.59)	381.51 (301.61–417.74)		

Table 2. *Cont.*

Severity Scores	Preoperative Median (IQR)	Postoperative Median (IQR)	Spearman Coefficient (rs)	*p*-Value
		TISS-28		
Category 2 (*n* = 13) Category 3 (*n* = 11) Category 4 (*n* = 8)	180.49 (122.47–283.59) 152.02 (111.04–185.39) 238.39 (161.97–273.59)	222.29 (182.90–294.48) 220.79 (177.76–326.44) 381.51 (301.61–417.74)	Pre: 0.227 Post: 0.394	Pre: 0.212 Post: **0.026**

IQR = Interquartile Range (25th Percentile–75th Percentile). Bold *p*-values indicate a statistically significant correlation ($p < 0.05$).

3. Discussion

Clinical scales play a crucial role in nursing practice, as they provide a systematic and standardized approach to patient assessment and care, resulting in more effective healthcare. The adoption of instruments provides an objective basis for planning and implementing interventions since the classification of patients using scales prioritizes areas of care, allowing professionals to define priority needs in addition to stratifying risk, guiding conduct, allowing monitoring of clinical progress, improving communication between teams, and thus contributing to patient safety [11]. Thus, the adoption of scales such as RACHS-1 and TISS-28 can help nurses make decisions.

The study carried out by Bajrachary, Joshi & Pradhan (2023) [12], which evaluated 2417 children undergoing congenital heart surgery in a tertiary specialized care service in Nepal, stands out. To this end, the authors used the RACHS-1, which proved to be a useful tool for predicting hospital mortality since, as well as enabling surgical risk stratification, it also allowed for the early planning of interventions and therapeutic measures. Data showed a significant disparity in mortality rates in different RACHS-1 categories since the more complex the surgical procedure, the higher the mortality rate, confirming the importance of effective risk stratification for planning specific interventions according to the patient's needs [13].

The adoption of scales, such as the TISS-28, which seeks to measure nursing workload, helps to plan care practices. However, in addition to subsidizing the planning and distribution of nursing teams, a study by Soares (2010) [14] showed that this instrument can also be used to identify patient severity and the likelihood of death, since the higher the score obtained on the TISS-28, the higher the mortality rate. The applicability of the scale is proven by a study carried out in an ICU in Brazil, which showed an accuracy of 99.1% of the TISS-28 when assessing patients who died, with sensitivity levels of 95% and specificity of 98%. The accuracy of the scale is the same in both ICUs and emergency rooms, but it is more sensitive in intensive care [15].

In addition to the use of scales, the measurement of biomarkers plays an important role in clinical assessment since they are measurable and objective indicators of biological processes, pathological conditions, or responses to therapeutic intervention. Thus, sTREM-1 stands out since infectious and inflammatory stimuli can lead to its activation, which makes it a valuable diagnostic parameter for monitoring macrophage activation in inflammatory conditions [16]. It is recognized that major surgery induces, to varying degrees, an inflammatory response since variations in volume, temperature, plasma composition and changes in tissue blood flow are present and result in important pathophysiological consequences [1].

Understanding the main events that induce tissue damage is certainly the first step in trying to optimize the diagnosis, management, and prognosis of potentially serious conditions, especially in high-risk patients such as critically ill children. Although several studies have addressed the role of sTREM-1 in pediatric patient populations, the impact of this marker in the context of pediatric cardiac surgery is still scarce [17].

The number of studies comparing data from the measurement of sTREM-1 with the RACHS-1 and TISS-28 scales, which are widely used in patients with congenital heart disease admitted to the pediatric ICU, is still incipient. However, several studies have evaluated the association and correlation between sTREM-1 and the severity scales widely used in the context of critically ill patients, which demonstrates its usability in this group of patients and possibilities for its use in stratifying severity and assessing the risk of death [18–24].

This study found that both pre- and postoperative mean sTREM-1 values were higher in the group of patients classified in category 4 of the TISS-28 when compared to those distributed in lower strata, showing that patients with higher sTREM-1 values preoperatively were classified as more severe postoperatively, since patients in category 4 of the TISS-28 had the highest mean sTREM-1 values.

The measurement of sTREM-1 shows important clinical applicability, especially in patients undergoing cardiac surgery, as evidenced by Golovkin et al. (2012) [24], who in their study highlighted the increase in the biomarker in the postoperative period, even among those who did not have septic complications. Pre- and postoperative dosing also showed that, as sTREM-1 increased, the patient was more likely to develop Systemic Inflammatory Response Syndrome (SIRS).

Other scales have shown an association with sTREM-1, as highlighted by Rios-Toro et al. (2017) [16], who identified a correlation between baseline serum levels of the biomarker and the Sequential Organ Failure Assessment (SOFA) score ($p < 0.001$), as well as with the Acute Physiology and Chronic Health Evaluation (APACHE-II) score ($p = 0.001$). Corroborating this, Charles et al. (2016) [18] determined that the level of sTREM-1 and the value of the Simplified Acute Physiology Score (SAPS-II) were the only independent predictors of death after adjusting for potential confounding factors, also noting that a decrease in sTREM-1 was more pronounced in survivors than in non-survivors. Another similar study by Jeydinak et al. (2018) [21] found that sTREM-1 levels were higher in non-survivors than in survivors (773 vs. 391, $p < 0.001$).

In septic patients, Jeydinak et al. (2019) [25] showed that sTREM-1 correlated positively with APACHE-II, SAPS-II, and SOFA scores ($p = 0.001$). At inclusion, the significant AuROC for predicting 28-day mortality was 0.772 for sTREM-1 (95% CI 0.672–0.871), 0.858 for APACHE-II (95% CI 0.768–0.948), 0.847 for SAPS-II (95% CI 0.733–0.96), and 0.806 for SOFA (95% CI 0.698–0.915), which leads to the conclusion that sTREM-1 can be an early predictor of 28-day sepsis mortality.

In individuals diagnosed with pneumonia, Zhang et al. (2022) [23] observed that the plasma level of sTREM-1 and the APACHE-II and SOFA scores were significantly higher in patients with severe pneumonia compared to those who developed the milder form ($p < 0.05$). In addition, there was a positive correlation between sTREM-1 and SOFA scores ($p < 0.05$). Wei et al. (2023) [22], evaluating patient survival and multiple organ failure (MOF), showed that sTREM-1 expressions in the death group were higher than those in the survival group ($p < 0.05$). Correlation analysis indicated that sTREM-1 had a high correlation with the SOFA score ($p < 0.05$), as observed by Khutornaya et al. (2023) [26], when patients with MOF had higher serum sTREM-1 compared to those without MOF in the pre- and post-surgical intervention stages ($p < 0.0001$).

In addition to being used in the context of sepsis, the measurement of sTREM-1 has shown an association with the risk of early neurological deterioration, as evidenced by a study carried out by Fan, Liu, Wang & Mei (2023) [19] in patients with stroke. The authors pointed out that higher levels of sTREM-1 were significantly associated with an increased risk of early neurological deterioration, according to the multivariate logistic regression model (OR, 4.19; 95% CI, 1.46–9.84; $p = 0.003$).

To determine whether the plasma concentration of sTREM-1 could predict the outcome of patients hospitalized with COVID-19, Gibot et al. (2023) [10] determined that the plasma concentration of sTREM-1 was higher in ICU patients than in ward patients (224 pg/mL (IQR 144–320) vs. 147 pg/mL (76–249), $p < 0.0001$) and higher in patients with a complicated outcome in both cohorts: 178 (94–300) vs. 135 pg/mL (70–220), $p < 0.0001$ in ward patients and 342 (288–532) vs. 206 pg/mL (134–291), $p < 0.0001$ in ICU patients. Elevated baseline concentration of sTREM-1 was an independent predictor of complicated outcomes (hazard ratio (HR) = 1.5 (1.1–2.1), $p = 0.02$ in ward patients; HR = 3.8 (1.8–8.0), $p = 0.0003$ in ICU patients). In the ICU, the cut-off point of 287 pg/mL had a sensitivity of 78% and a specificity of 74% for death.

The non-linear increase in postoperative sTREM-1 levels, characterized by an abrupt, almost twofold increase exclusively in category 4 of both scores, with relatively stable levels between categories 1 and 3, is indeed a finding that highlights the specific biological role of this biomarker.

Our hypothesis is that this phenomenon represents a biological threshold response, driven by the following pathophysiological mechanisms: Category 4 in the RACHS-1 and TISS-28 scores represents a critical escalation in surgical complexity, tissue injury, and therapeutic vulnerability. On the other hand, the difference in physiological stress between categories 1, 2, and 3 is substantially smaller. TREM-1 is not a constitutive marker of mild inflammation; it acts as an amplifier of the innate immune response, released primarily during massive cellular activation. Our data suggest that surgical trauma and ischemia–reperfusion injury triggered in categories 1 to 3 do not exceed the critical biological trigger required for massive sTREM-1 cleavage. However, the extreme physiological insult inherent in category 4 procedures exceeds this limit.

While the elevated postoperative concentrations of sTREM-1 observed in our cohort could be pathophysiologically linked to underlying factors such as bacteremia, infectious sepsis, or severe aseptic systemic inflammation triggered by cardiopulmonary bypass, exploring these specific clinical boundaries fell outside the delimited scope of the present study. To maintain a strict thematic focus, these confounding variables and their subsequent clinical outcomes were comprehensively evaluated as independent endpoints in parallel arms of our wider research project (such as in previously published and accepted data from our group). Consequently, this investigation was intentionally restricted to a baseline, exploratory mapping of how sTREM-1 reflects the biological stress and risk strata inherently categorized by the RACHS-1 and TISS-28 scoring systems.

The main limitations of this study include the relatively small sample size, which restricts the statistical power for highly stratified analyses and limits the generalizability of the results. Due to the small cohort and the non-parametric nature of the sTREM-1 distribution, multiple pairwise comparisons between individual categories of RACHS-1 and TISS-28 would severely compromise statistical power and inflate Type I error rates. To mitigate this risk, we employed a global ordinal correlation approach (Spearman's coefficient) rather than multiple post hoc pairwise tests. Nonetheless, the significant findings obtained in the postoperative period ($p = 0.045$ for RACHS-1 and $p = 0.026$ for TISS-28) are borderline and should be interpreted with caution within the scope of an exploratory study.

Additionally, a complete overlap of patients was observed in the highest severity categories (C3 and C4) between both scoring systems, which reflects an intrinsic characteristic of our specific sample and prevents an independent evaluation of these tools. The single-center design and the exclusion of patients with major comorbidities or genetic syndromes may introduce selection bias, potentially limiting the representativeness of the cohort. Furthermore, the cross-sectional timing of the perioperative measurements

precludes any causal inferences. Finally, the heterogeneity of congenital heart defects and surgical procedures was not fully stratified or adjusted in the analysis. Because different cardiac anomalies and surgical corrections trigger distinct inflammatory responses, this heterogeneity may act as a potential confounding factor. Despite these constraints, the evaluation of biomarkers like sTREM-1 remains a promising approach for clinical assessment and risk stratification in critically ill pediatric patients. While this study provides encouraging exploratory data, further large-scale, multicenter investigations conducted outside a pandemic context are required to validate the clinical utility of sTREM-1, both alone and integrated with validated prognostic scores.

4. Materials and Methods

This is a translational, cross-sectional, exploratory study of 32 children aged between zero and 14 with congenital heart disease who underwent surgical correction at a public referral hospital in the northeast of Brazil, which provides care for individuals with cardiovascular diseases in various life cycles through the Brazilian Unified Health System (SUS).

The study consisted of individuals of both sexes with a medical diagnosis of congenital heart disease and an indication for partial or total cardiac surgical correction. Children with rare genetic syndromes, with an infectious diagnosis at the time of admission, or who had already undergone palliative or total correction surgery before the data collection period were excluded. The study population consisted of all the children with congenital heart disease seen at the health service over the 17-month period, which totaled 45 patients. However, after defining the inclusion and exclusion criteria as well as the consent of family members, the sample consisted of 32 children.

Data was collected between June 2021 and November 2022 using a structured instrument with sociodemographic variables (age, gender, color, municipality and state of residence) and clinical variables (type of surgery, surgical complications, presence of cyanosis and laboratory tests). In addition, the TISS-28 was used, an instrument developed in the 1970s and validated and adapted to Brazilian Portuguese. It consists of seven dimensions, namely, basic activities, ventilatory support, cardiovascular support, renal support, neurological support, metabolic support and specific interventions, with a score ranging from 0 to 76 points, where the higher the score, the greater the need for care. Patients can be stratified into four classes according to the need for monitoring and care.

According to the author's recommendation, Class I is intended for those with a score between zero and 19 points; Class II is between 20 and 34 points; Class III is between 35 and 60 points; and, finally, Class IV is for patients who scored more than 60 [6]. To predict the risk of postoperative mortality in congenital heart disease, we chose to use the RACHS-1, an instrument that categorizes surgical procedures and the risk of hospital mortality into six classes. This data was collected retrospectively, within 24 h of the patient being admitted to the Intensive Care Unit (ICU).

To determine the value of sTREM-1 and its kinetics in the pre- and postoperative periods, blood samples were taken 24 h before the procedure, as well as in the immediate postoperative period. The blood samples were then centrifuged to obtain serum and plasma and then stored at −80.0 °C. To measure sTREM-1, the Enzyme-Linked Immunosorbent Assay (ELISA) method was used, using the commercial Human TREM-1 ELISA Kit (DuoSet®ELISA Development System, R&D Systems®, a Bio-techne® Brand, Minneapolis, MN, USA), according to the manufacturer's instructions. A Wellwash microplate reader (Thermo Fisher Scientific Oy, Vantaa, Finland) was used.

The data collected was compiled and stored in Microsoft Office Excel software and then imported into the Statistical Package for the Social Sciences—SPSS version 29.0 computer system, as it is suitable for achieving the study's objectives and enables the accuracy and

generalization of its results. The data were analyzed using a quantitative approach, using descriptive statistics of a univariate nature for all the variables.

Continuous variables were initially subjected to the Shapiro–Wilk test to verify the symmetry and normality of the data distribution. Given the identification of a predominantly non-normal distribution in most analytical strata ($p < 0.05$), the concentrations of the sTREM-1 biomarker were expressed as median values and interquartile range (IQR, corresponding to the 25th and 75th percentiles). In order to mitigate the risk of Type I error resulting from multiple simultaneous paired comparisons, the assessment of the relationship between perioperative sTREM-1 levels and the severity categories of the RACHS-1 and TISS-28 ordinal scores was performed globally using Spearman's rank correlation coefficient (r_s). All statistical analyses were performed two-tailed, adopting a significance level of 5% ($p < 0.05$).

For the formulation of the graphic summary, we used the NotebookLM tool (https://notebooklm.google.com/), through the inclusion of a descriptive summary of the main findings. The images were formatted with the following prompt according to the software settings: language: English; orientation: landscape; level of detail: detailed; and infographic characteristics: theme in blue, with horizontal axes (lines) and highlighting the main statistical values.

5. Conclusions

In conclusion, postoperative sTREM-1 levels correlated significantly with surgical risk and clinical severity, showing higher median concentrations in patients classified into more severe categories according to both RACHS-1 and TISS-28 scores. Conversely, no statistically significant correlation was observed in the preoperative period. These findings suggest that sTREM-1 may serve as a biomarker primarily reflecting postoperative inflammatory responses and surgical complexity rather than baseline preoperative risk.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/physiologia6020041/s1, Table S1: Normality analysis of the data.

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Institutional Review Board Statement: This study was performed in line with the principles of the Declaration of Helsinki. It should be noted that throughout the research process, especially during the empirical information collection phase, the ethical aspects that regulate research involving human beings set out in Resolution 466/2012 of the CNS/MS/BRASIL were observed, especially the secrecy and confidentiality of information. This study was evaluated and approved by the Research Ethics Committee of the HUOC/PROCAPE Hospital Complex, Recife, Pernambuco, Brazil, under approval number 4.734.401 and CAAE: 43277121.1.0000.5192 (26 May 2021).

Informed Consent Statement: All participants agreed to take part in the study by signing the Free and Informed Consent Form (FICF) and the Informed Consent Form (ICF).

Data Availability Statement: Dataset available on request from the authors.

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The authors reviewed and edited the result and assume full responsibility for the content of this publication.

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Abbreviations

APACHE II	Acute Physiology and Chronic Health Evaluation II
CHD	Congenital Heart Defects
COVID-19	Coronavirus Disease 2019
ELISA	Enzyme-Linked Immunosorbent Assay
HR	Hazard ratio
ICU	Intensive Care Unit
MOF	Multiple Organ Failure
RACHS-1	Risk Adjusted Congenital Heart Surgery Score-1
SAPS II	Simplified Acute Physiology Score II
SIRS	Systemic Inflammatory Response Syndrome
SOFA	Sequential Organ Failure Assessment
sTREM-1	Soluble Triggering Receptor Expressed on Myeloid Cells-1
SUS	Unified Health System
TISS-28	Therapeutic Intervention Scoring System

References

1. Cabral, J.V.B.; Guimarães, A.L.S.; Sobral-Filho, D.C.; dos Santos, A.C.O. Mortality due to congenital heart disease in Pernambuco from 1996 to 2016. *Rev. Assoc. Médica Bras.* **2020**, *66*, 931–936. [CrossRef] [PubMed]
2. Santos, C.F.; Novais, M.C.M.; Carvalho, P.A.F.; Gomes Neto, M.; Correia, H.F. Incidence, associated factors and impact of pulmonary complications in the postoperative period of pediatric cardiac surgery. *Ciência Médica Biológica* **2022**, *21*, 25–30. [CrossRef]
3. Luz, V.B.S.; Brunori, E.H.F.R.; Simonetti, S.H.; França, J.I.D. Predictors of complications in the postoperative period of pediatric cardiac surgery. *Nursing* **2022**, *25*, 7678–7691. [CrossRef]
4. Covalski, D.; Pauli, E.; Echer, A.K.; Nogueira, R.R.; Fortes, V.L.F. Postoperative period of cardiac surgeries: Prevalent complications within 72 hours. *Rev. Enferm. UFSM* **2021**, *11*, e75. [CrossRef]
5. Araújo, M.E.S.; Maximiano, L.C.S.; Oliveira, C.J.L.; Queiroz, J.C.; Pereira, A.M.F.C.; Vieira, A.N. Clinical severity profile of patients admitted to an Intensive Care Unit. *Res. Soc. Dev.* **2021**, *10*, e58410313759. [CrossRef]
6. Nunes, B. Translation into Portuguese and Validation of a Severity Measurement Instrument in the ICU: TISS-28—Therapeutic Intervention Scoring System. Master's Thesis, University of São Paulo, São Paulo, Brazil, 2000.
7. Geier, L.; Menzel, C.; Germund, I.; Trieschmann, U. RACHS-1 score as predictive factor for postoperative ventilation time in children with congenital heart disease. *Cardiol. Young* **2020**, *30*, 213–218. [CrossRef]
8. Jenkins, K.J. Risk adjustment for congenital heart surgery: The RACHS-1 method. *Semin. Thorac. Cardiovasc. Surg. Pediatr. Card. Surg. Annu.* **2004**, *7*, 180–184. [CrossRef]
9. Cabral, J.V.B.; Silveira, M.M.B.M.; Xavier, A.T.; Assunção, N.; Sobral-Filho, D.C.; Oliveira, D.C. Triggering receptor expressed on myeloid cells-1 as a pediatric sepsis biomarker. *Rev. Assoc. Médica Bras.* **2021**, *67*, 449–453. [CrossRef] [PubMed]
10. Gibot, S.; Lafon, T.; Jacquin, L.; Lefèvre, B.; Kimmoun, A.; Guillaumot, A.; Losser, M.R.; Douplat, M.; Argaud, L.; De Ciancio, G.; et al. Soluble TREM-1 plasma concentration predicts poor outcome in COVID-19 patients. *Intensive Care Med. Exp.* **2023**, *11*, 32. [CrossRef]
11. Gardona, R.G.B.; Barbosa, D.A. The importance of clinical practice supported by health assessment tools. *Rev. Bras. Enferm.* **2018**, *71*, 1815–1816. [CrossRef] [PubMed]
12. Bajracharya, S.M.; Joshi, D.; Pradhan, S. Predicting surgical mortality after congenital heart surgeries using Risk Adjustment in Congenital Heart Surgery-1 (RACHS-1) risk scoring system: A retrospective analysis in a single tertiary center. *Nepal. Heart J.* **2023**, *20*, 27–31. [CrossRef]
13. Jacobs, J.P.; Jacobs, M.L.; Lacour-Gayet, F.G.; Jenkins, K.J.; Gauvreau, K.; Bacha, E.; Maruszewski, B.; Clarke, D.R.; Tchervenkov, C.I.; Gaynor, J.W.; et al. Stratification of complexity improves the utility and accuracy of outcomes analysis in a multi-institutional congenital heart surgery database: Application of the Risk Adjustment in Congenital Heart Surgery (RACHS-1) and Aristotle Systems in the Society of Thoracic Surgeons (STS) Congenital Heart Surgery Database. *Pediatr. Cardiol.* **2009**, *30*, 1117–1130. [CrossRef] [PubMed]

14. Soares, L.C.C.; Ribas, D.; Spring, R.; Silva, J.M.F.; Miyague, N.I. Clinical profile of systemic inflammatory response after pediatric cardiac surgery with cardiopulmonary bypass. *Arq. Bras. Cardiol.* **2010**, *94*, 127–133. [CrossRef]
15. Chianca, T.C.M.; Guedes, H.M.; Souza, K.M.; de Morais, S.S.; Ercole, F.F. Severity Assessment of Patients Admitted to the Clinics of a Hospital. *Cienc. Enfermería* **2015**, *21*, 11–21. [CrossRef]
16. Ríos-Toro, J.J.; Márquez-Coello, M.; García-Álvarez, J.M.; Martín-Aspas, A.; Rivera-Fernández, R.; Sáez de Benito, A.; Girón-González, J.A. Soluble membrane receptors, interleukin 6, procalcitonin and C reactive protein as prognostic markers in patients with severe sepsis and septic shock. *PLoS ONE* **2017**, *12*, e0175254. [CrossRef]
17. Pontrelli, G.; De Crescenzo, F.; Buzzetti, R.; Calò-Carducci, F.; Jenkner, A.; Amodio, D.; De Luca, M.; Chiurchiù, S.; Davies, E.H.; Simonetti, A.; et al. Diagnostic value of soluble triggering receptor expressed on myeloid cells in paediatric sepsis: A systematic review. *Ital. J. Pediatr.* **2016**, *42*, 44. [CrossRef] [PubMed]
18. Charles, P.E.; Noel, R.; Massin, F.; Guy, J.; Bollaert, P.E.; Quenot, J.P.; Gibot, S. Significance of soluble triggering receptor expressed on myeloid cells-1 elevation in patients admitted to the intensive care unit with sepsis. *BMC Infect. Dis.* **2016**, *16*, 559. [CrossRef]
19. Fan, L.; Liu, Y.; Wang, Z.; Mei, X. Prognostic utility of sTREM-1 in predicting early neurological deterioration in patients with acute ischemic stroke treated without reperfusion therapy. *J. Stroke Cerebrovasc. Dis.* **2023**, *32*, 107381. [CrossRef]
20. Li, L.; Chen, J.; OuYang, B.; Chen, M.; Guan, X.; Zhu, Z. Diagnostic value of soluble triggering receptor expressed on myeloid cells-1 in critically-ill, postoperative patients with suspected sepsis. *Am. J. Med. Sci.* **2013**, *345*, 178–184. [CrossRef]
21. Jedynak, M.; Siemiatkowski, A.; Mroczko, B.; Groblewska, M.; Milewski, R.; Szmitkowski, M. Soluble TREM-1 serum level can early predict mortality of patients with sepsis, severe sepsis and septic shock. *Arch. Immunol. Ther. Exp.* **2018**, *66*, 299–306. [CrossRef]
22. Wei, Y.; Xiao, P.; Wu, B.; Chen, F.; Shi, X. Significance of sTREM-1 and sST2 combined diagnosis for sepsis detection and prognosis prediction. *Open Life Sci.* **2023**, *18*, 20220639. [CrossRef]
23. Wang, Z.; Chang, B.; Zhang, Y.; Chen, J.; Xie, F.; Xiang, Y.; Liu, T.; Li, Y. Clinical value of serum sTREM-1 and HBP levels in combination with traditional inflammatory markers in diagnosing hospital-acquired pneumonia in elderly. *BMC Infect. Dis.* **2022**, *22*, 773. [CrossRef]
24. Golovkin, A.S.; Matveeva, V.G.; Grigoriev, E.V.; Shukevich, D.L.; Bayrakova, Y.V.; Barbarash, L.S. sTREM-1 as a prognostic marker of postoperative complications in cardiac surgery. *ISRN Inflamm.* **2012**, *2012*, 382862. [CrossRef] [PubMed]
25. Jedynak, M.; Siemiątkowski, A.; Milewski, R.; Mroczko, B.; Szmitkowski, M. Diagnostic effectiveness of soluble triggering receptor expressed on myeloid cells-1 in sepsis, severe sepsis and septic shock. *Arch. Med. Sci.* **2019**, *15*, 713–721. [CrossRef] [PubMed]
26. Khutornaya, M.V.; Sinitsky, M.Y.; Sinitskaya, A.V.; Asanov, M.A.; Ponasenko, A.V.; Grigoriev, E.V. TREM-1 as a Marker of Multiple Organ Failure in Cardiac Surgery. *Immunol. Investig.* **2023**, *52*, 583–597. [CrossRef]

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