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Association Between STAT Mortality Score and Noninvasive Ventilation Failure After Congenital Heart Disease Surgery in Children

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Abstract

Aim: The aim of this study is to determine whether there is an association between STAT (Society of Thoracic Surgeons–European Association for Cardio-Thoracic Surgery) metrics and noninvasive ventilation (NIV) failure, and to describe the factors influencing this outcome in pediatric patients undergoing congenital heart disease (CHD) surgery at a federal referral hospital.

Study Design: This analytical cross-sectional study included patients under 18 years of age with CHD who underwent corrective or palliative surgery and required postoperative NIV support between January 2020 and December 2022. The type of ventilation (prophylactic or therapeutic NIV) was determined by the multidisciplinary clinical team based on surgical complexity, hemodynamic stability, and the patient's respiratory status. Continuous quantitative and dichotomous qualitative variables were analyzed using descriptive and inferential statistics (multivariate logistic regression). The R statistical package, version 4.4.1, was used with a 95% confidence level.

Results: A total of 110 patients (mean age: 18 months; mean weight: 8 kg) met the inclusion criteria. NIV failure occurred in 21% of cases, predominantly due to respiratory causes. STAT Categories 2, 3, 4, and 5 showed no statistically significant association with NIV failure ($p>0.05$). Clinical relevance was noted for NIV duration (odds ratio [OR]=1.06), mechanical ventilation duration (OR=1.01), and intensive care unit (ICU) length of stay (OR=1.01).

Conclusions: No significant association was found between the STAT Mortality Score and Categories and NIV failure. Although mechanical ventilation duration, NIV duration, and ICU length of stay showed a weak positive association (OR=1.01–1.06), these values indicate minimal clinical impact. These findings suggest that while STAT metrics may assist in patient risk stratification, other postoperative factors play a greater role in predicting NIV failure.

Keywords: Congenital; Health care; Heart defects; Noninvasive ventilation; Postoperative period; Quality indicators.

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Introduction

Congenital heart diseases (CHD) encompass a wide range of structural cardiac abnormalities.[1] Approximately 80% of patients with CHD require surgical intervention during their lifetime, and about half of these procedures occur within the first year of life, either for corrective or palliative purposes.[2]

In the early 2000s, researchers developed several tools to assess outcomes following CHD surgery.[3-4] Among them, the Risk Adjustment for Congenital Heart Surgery (RACHS-1) categories and the Aristotle Basic Complexity (ABC) levels became widely used.[1] However, because these classifications were primarily based on expert opinion, they presented limitations in objectively reflecting clinical outcomes.[1] To address this gap, an empirically derived model—the Society of Thoracic Surgeons–European Association for Cardio-Thoracic Surgery (STAT) Mortality Score and Categories—was introduced, providing more accurate and data-driven outcome predictions.[5] This model was later refined to reflect contemporary results.[1]

Based on estimated mortality rates, each surgical procedure receives a numerical score ranging from 0.1 to 5.0, subsequently grouped into five risk categories[5] (Table 1). Category 1 represents the lowest mortality risk (0.2%–1.3%), while Category 5 indicates the highest (13.5%–38.7%).[1-5] The STAT metrics have since been widely adopted in clinical research and quality improvement initiatives.[6-8]

Surgical outcomes in CHD patients depend not only on the anatomical complexity of the defect but also on preexisting conditions and postoperative clinical progression.[9] Mechanical ventilation plays a crucial role in maintaining hemodynamic stability; however, prolonged ventilation may negatively impact recovery.[10] Numerous studies emphasize the benefits of early extubation in reducing complications and shortening intensive care unit (ICU) stays.[11] Nonetheless, patients remain at risk for post-extubation respiratory failure,[12] and noninvasive ventilation (NIV) serves as an important supportive therapy in this context.

NIV helps preserve the cardiopulmonary advantages of positive pressure ventilation while reducing respiratory failure and reintubation rates.[13] However, when NIV fails, escalation to invasive mechanical ventilation becomes necessary, leading to longer ICU stays and increased mortality.[14-15]

Given this clinical relevance, this study aimed to assess whether there is an association between the STAT Mortality Score and Categories and NIV failure in pediatric patients undergoing surgery for congenital heart disease at a federal referral hospital. Additionally, it sought to identify the clinical factors influencing this outcome.

Materials and Methods

This analytical cross-sectional study evaluated both the exposure factor (STAT Mortality Score and Categories) and the outcome (noninvasive ventilation failure) simultaneously. The study was conducted at a specialized referral center for congenital heart diseases, covering the period from January 1, 2020, to December 31, 2022. The outcome, NIV failure, was defined as the need for orotracheal intubation during prophylactic or therapeutic noninvasive support, regardless of the duration of NIV use.

The study was approved by the from Ethics Committee of National Institute of Cardiology (Approval Number: 68156623.5.0000.5272, Date: 31.03.2023), and all procedures complied with the principles of the Declaration of Helsinki. Due to the study's retrospective nature, informed consent was not applicable or required by the ethics committee. We did not use artificial intelligence in the production of this research.

Table 1. Examples of procedures included in the STAT Mortality Score and Categories

STAT Category	Representative Procedures	STAT Score Range	Estimated Mortality Risk (% range)
1	ASD repair, VSD repair, Coarctation repair	0.1–0.3	0.2–1.3
2	Bidirectional Glenn, Fontan procedure, Rastelli	0.3–0.5	1.4–2.6
3	Arterial switch operation, Tetralogy of Fallot with conduit	0.6–0.9	2.7–5.0
4	AVSD complete repair, Norwood stage I	1.0–1.4	6.0–12.0
5	Complex single-ventricle palliation, Cardiac transplant	2.1–5.0	13.5–38.7

ASD: Atrial Septal Defect; AVSD: Atrioventricular Septal Defect; VSD: Ventricular Septal Defect.

Study Population

Patients under 18 years of age with congenital heart disease who underwent corrective or palliative cardiac surgery and required postoperative NIV support were eligible for inclusion.

Exclusion criteria included patients transferred to another hospital while still on NIV and those who remained on noninvasive support after the study period.

Ventilation Type Selection Criteria

The decision regarding the type of noninvasive ventilation—prophylactic (initiated immediately after extubation to prevent respiratory failure) or therapeutic (initiated in response to clinical signs of respiratory distress)—was made by the multidisciplinary intensive care team. This decision was based on factors such as:

- the complexity of the surgical procedure,
- the patient's hemodynamic stability, and
- their pre- and postoperative respiratory condition.

This individualized approach ensured that ventilatory management reflected real clinical practice, allowing evaluation of the STAT score as a complementary predictor of NIV outcomes.

Sample Size

Sample size was calculated using WinPepi version 3.18, a public-domain statistical package for epidemiological analysis. Based on a previously reported NIV requirement prevalence of 21.4%,[13] a 5% margin of error, and a 95% confidence level, the minimum estimated sample size was 33 participants.

Data Collection

Patient data were obtained from a prospectively maintained institutional database containing clinical information collected throughout hospitalization. The database, securely stored in the cloud, is accessible to the multidisciplinary team upon request.

Variables were classified as either continuous quantitative or categorical qualitative:

- Continuous variables: age, weight, duration of mechanical ventilation, duration of NIV, and ICU length of stay.
- Categorical variables: sex, STAT category and score, type of surgery (corrective or palliative), presence of diaphragmatic paralysis, ventilatory status before and immediately after surgery, open chest status, use of extracorporeal membrane oxygenation (ECMO) in the immediate postoperative period, post-extubation ventilatory status (room air, oxygen therapy, or NIV), type of NIV (continuous positive airway pressure [CPAP] or bilevel), causes of NIV failure (respiratory, hemodynamic, infectious, or neurological), and final hospital outcome (ICU, discharge to ward, transfer, or death).

Statistical Analysis

Descriptive and exploratory analyses were performed using absolute (n) and relative (%) frequencies, measures of central tendency (mean and median), and measures of dispersion (standard deviation). The chi-square test, t-test, and Mann–Whitney U test were used as appropriate. Statistical significance was set at $p \leq 0.05$, with a 95% confidence interval.

For inferential analysis, a multivariate logistic regression model was applied to evaluate factors associated with NIV failure, adjusting for potential confounders. The effects of the association between STAT metrics and NIV failure, for variables with significance below 5% in the statistical tests, were included in the multivariate logistic regression model. We conducted the statistical analyses using the R statistical package, version 4.4.1.

Results

Of the 640 patients initially screened, 77% underwent corrective or palliative cardiac surgery. Among these, 111 met the inclusion criteria. One patient was excluded due to transfer to another hospital unit while still receiving NIV support, resulting in a final sample of 110 patients (Fig. 1).

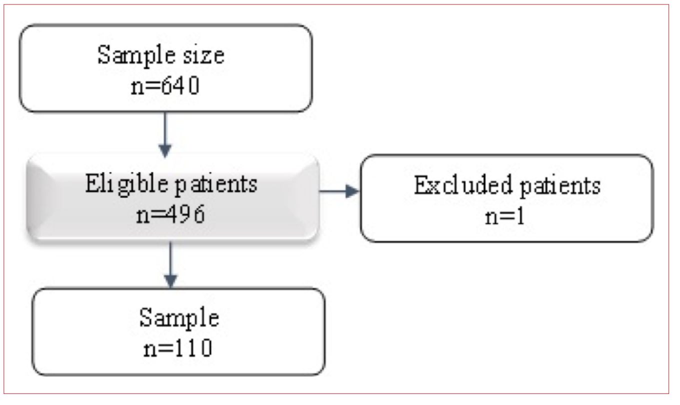

Figure 1. Patient recruitment process flowchart.

Study Patients' Characteristics

As shown in Table 2, most patients were male, with a mean age of 18 months and a mean weight of 8 kg. No single STAT category predominated; patients were distributed across all five risk categories, ranging from 4.54% to 37.27%.

- In Category 1, the most frequent score was 0.1.
- In Category 2, the predominant score was 0.3.
- In Category 3, it was 0.9,
- In Category 4, 1.2.
- In Category 5, 3.0.

Corrective surgeries were more frequent than palliative ones. Most patients required mechanical ventilation preoperatively and immediately postoperatively, with a mean duration of less than 12 days. Following extubation, NIV was the most commonly used ventilatory modality, predominantly in the bilevel mode. Nearly 90% of patients were successfully discharged to the ward, with one recorded death.

NIV failure occurred in 21% of patients. Compared to those with successful NIV, the failure group was characterized by younger age, lower weight, and longer durations of mechanical ventilation, NIV use, and ICU stay. Approximately 40% of the patients who experienced NIV failure belonged to STAT Category 2, most commonly with a score of 0.3. Corrective cardiac surgery, pre-surgical intubation, and discharge to the ward as the final hospital outcome were predominant characteristics in this group.

The main causes of NIV failure were:

- Respiratory factors (60.87%),
- Hemodynamic factors (21.74%),
- Infectious causes (8.69%),
- Neurological causes (4.35%), and
- A combination of respiratory and hemodynamic factors (4.35%).

Logistic Regression Analysis

A multivariate logistic regression model was applied to estimate the likelihood of NIV failure according to clinical characteristics (Table 3). None of the variables reached statistical significance ($p<0.05$). However, clinical relevance was observed for the duration of mechanical ventilation, NIV duration, and ICU length of stay. Specifically, each additional day of NIV use increased the likelihood of failure by 6% (odds ratio [OR]=1.06).

Discussion

This analytical cross-sectional study examined the prevalence of noninvasive ventilation failure and the clinical factors associated with it in pediatric patients undergoing congenital heart disease surgery. Additionally, it investigated whether the STAT Mortality Score and Categories were associated with NIV failure.

The observed NIV failure rate (21%) was comparable to findings in previous studies. Ódena et al.,[16] Yañez et al.,[17] Lum et al.,[18] Pancera et al.,[19] and Gupta et al.[20] reported failure rates around 30%, while Fernández Lafever et al.[13]—whose study design and patient population closely resemble ours—reported a 15% failure rate in pediatric cardiac surgery patients.

The incidence of NIV failure in postoperative pediatric cardiac populations tends to be higher than in other pediatric groups.[21-26] Several factors contribute to this, including younger age, hemodynamic instability, increased extubation failure rates, and the presence of genetic syndromes.[27]

Positive pressure ventilation has well-known cardiovascular effects. Increased intrathoracic pressure can raise ventricular afterload, pulmonary vascular resistance, and myocardial oxygen demand.[13,28] These changes may compromise hemodynamics in children recovering from cardiac surgery, leading to NIV failure in vulnerable patients.

Early extubation in pediatric cardiac surgery has been widely studied and is associated with improved outcomes.[29] However, orotracheal intubation in the immediate postoperative period remains common due to surgical complexity, young age, low weight, preoperative critical illness, respiratory failure, or infections.[29,30] In this study, patients in the NIV failure group were generally younger and lighter, and most had required mechanical ventilation immediately postoperatively. These factors likely contributed to prolonged ventilation, longer ICU stays, and an increased risk of NIV failure—relationships that demonstrated clinical relevance in our analysis, despite lacking statistical significance.

Table 2. Study patients' characteristics

Variable	Total (n=110)	NIV Failure (n=23)	No NIV Failure (n=87)
Male gender, n (%)	61 (55.45)	9 (39.13)	52 (59.77)
Age (months), Mean±SD (median)	18.62±40.16 (3)	10.64±31.86 (3)	20.76±42.01 (2.5)
Weight (kg), Mean±SD (median)	8.16±10.84 (4.1)	5.51±6.75 (3.8)	8.85±11.61 (4.2)
STAT Categories, n (%)			
Category 1	25 (22.73)	5 (21.74)	20 (22.99)
Category 2	41 (37.27)	9 (39.13)	32 (36.78)
Category 3	14 (12.73)	2 (8.7)	12 (13.79)
Category 4	25 (22.73)	6 (26.09)	19 (21.84)
Category 5	5 (4.54)	1 (4.34)	4 (4.6)
STAT Score, n (%)			
0.1/Category 1	13 (11.82)	3 (13.04)	10 (11.49)
0.2/Category 1	12 (10.91)	2 (8.70)	10 (11.49)
0.3/Category 2	28 (25.45)	6 (26.09)	22 (25.29)
0.4/Category 2	13 (11.82)	3 (13.04)	10 (11.49)
0.5/Category 3	1 (0.91)	0 (0)	1 (1.15)
0.6/Category 3	1 (0.91)	0 (0)	1 (1.15)
0.7/Category 3	3 (2.73)	0 (0)	3 (3.45)
0.9/Category 3	9 (8.18)	2 (8.70)	7 (8.05)
1.0/Category 4	2 (1.82)	0 (0)	2 (2.30)
1.1/Category 4	3 (2.73)	0 (0)	3 (3.45)
1.2/Category 4	14 (12.73)	5 (21.74)	9 (10.34)
1.3/Category 4	5 (4.55)	0 (0)	5 (5.75)
1.4/Category 4	1 (0.91)	1 (4.35)	0 (0)
2.1/Category 5	2 (1.82)	0 (0)	2 (2.30)
3.0/Category 5	3 (2.73)	1 (4.35)	2 (2.30)
Type of Surgery, n (%)			
Corrective	78 (70.91)	16 (69.57)	62 (71.26)
Palliative	32 (23.09)	7 (30.43)	25 (28.74)
Pre-Surgical Ventilatory Status, n (%)			
Orotracheal Intubation	75 (68.18)	5 (65.22)	60 (68.97)
Oxygen Therapy	16 (14.55)	4 (17.39)	12 (13.79)
Room Air	14 (12.72)	3 (13.04)	11 (12.64)
NIV	5 (4.55)	1 (4.35)	4 (4.60)
Immediate Postoperative Ventilatory Status, n (%)			
Orotracheal Intubation	104 (94.54)	22 (95.65)	82 (94.25)
Oxygen Therapy	4 (3.64)	1 (4.35)	3 (3.45)
NIV	2 (1.82)	0 (0)	2 (2.30)
MV Duration (days)*, Mean±SD (median)	11.46±16.07 (7)	17.65±27.46 (7)	9.82±11.02 (7)
Open Chest, n (%)	34 (30.91)	7 (30.43)	27 (31.03)
ECMO, n (%)	1 (0.91)	0 (0)	1 (1.15)
Diaphragmatic Paralysis	8 (7.27)	3 (13.04)	5 (5.75)
Post-Extubation Ventilatory Status, n (%)			
Oxygen Therapy	12 (10.91)	4 (17.39)	8 (9.20)
Room Air	10 (9.09)	3 (13.04)	7 (8.05)
NIV	88 (80)	16 (69.57)	72 (82.76)

Table 2. Study patients' characteristics (Cont.)

Variable	Total (n=110)	NIV Failure (n=23)	No NIV Failure (n=87)
NIV Modality, n (%)			
CPAP	52 (47.27)	14 (60.87)	38 (43.68)
Bilevel	58 (52.73)	9 (39.13)	49 (56.32)
NIV Duration (days)*, Mean±SD (median)	5.21±5.79 (3)	7.82±8.35 (4)	4.51±4.72 (3)
ICU Length of Stay (days)*, Mean±SD (median)	22.65±21.54 (16)	33.61±30.95 (26)	19.76±17.4 (16)
Hospital Outcome, n (%)			
ICU	2 (1.82)	0 (0)	2 (2.30)
Discharge to Ward	89 (80.91)	20 (86.96)	69 (79.31)
Transfer to Another Hospital Unit	18 (16.36)	2 (8.70)	16 (18.39)
Death	1 (0.91)	1 (4.35)	0 (0)

ECMO: Extracorporeal Membrane Oxygenation; Kg: Kilogram; MV: Mechanical Ventilation; n: Total; NIV: Noninvasive Ventilation; SD: Standard Deviation; ICU: Intensive Care Unit; %: Percentage. *p-value <0.05.

Table 3. Logistic regression model for NIV failure

Adjusted Variables	OR	p
STAT Category 2	0.75	0.67
STAT Category 3	0.37	0.31
STAT Category 4	0.55	0.46
STAT Category 5	0.52	0.61
MV duration (days)	1.01	0.51
NIV duration (days)	1.06	0.22
ICU length of stay (days)	1.01	0.64

ICU: Intensive Care Unit; MV: Mechanical Ventilation; NIV: Noninvasive Ventilation; OR: Odds Ratio.

Prolonged mechanical ventilation is associated with several complications, including pneumonia, ventilator-induced lung injury, diaphragmatic dysfunction, and generalized muscle weakness, all of which can hinder extubation and recovery.[31] Sedation and immobility may further delay weaning and contribute to respiratory muscle fatigue, ultimately predisposing patients to NIV failure.

NIV is widely used after pediatric cardiac surgery as a first-line or prophylactic therapy to avoid reintubation, providing positive pressure support without invasive airway instrumentation.[32] Its indications are generally classified as prophylactic—initiated immediately after extubation to prevent respiratory failure—or therapeutic, when applied in response to clinical signs of respiratory distress.[13] In high-risk postoperative populations, NIV use requires caution and close monitoring.[33]

Recent clinical studies comparing prophylactic versus therapeutic NIV in pediatric cardiac postoperative care indicate that prophylactic NIV may reduce the incidence of postoperative pulmonary complications (PPCs), particularly atelectasis, compared to usual care or conventional oxygen therapy. However, the evidence for reduction in reintubation rates or mortality remains of low-certainty and inconsistent across studies.

A 2023 network meta-analysis of randomized controlled trials found that prophylactic NIV after pediatric cardiac surgery significantly reduced PPCs (relative risk [RR] 0.67, 95% confidence interval [CI]: 0.49–0.93) and atelectasis (RR 0.65, 95% CI: 0.45–0.93), but did not significantly reduce reintubation rates or short-term mortality compared to standard care. The certainty of evidence was low to moderate, and the benefit over other modalities (such as high-flow nasal cannula [HFNC] or CPAP) was not definitive, though NIV ranked highest for PPC prevention.[34] Similarly, a 2024 systematic review focusing on pediatric cardiac surgery patients found no clear difference in reintubation rates between HFNC, conventional oxygen therapy, and NIV modalities, with very low certainty due to small sample sizes and study heterogeneity.[35] Another meta-analysis suggested that HFNC may reduce postextubation failure compared to other NIV techniques, but the evidence is limited and not specific to prophylactic versus therapeutic use.[36]

The STAT Mortality Score and Categories, which classify surgical procedures based on empirically derived mortality risk,[1] serve as valuable indicators of postoperative complexity and potential complications. In this study, prophylactic NIV was frequently initiated in patients with higher surgical complexity, aligning with findings from Fernández Lafever et al.,[13] who observed lower NIV failure rates in patients who received prophylactic NIV (16.4%) compared with those who did not (28.7%; p=0.046). Similarly, Mayordomo-Colunga et al.[37] reported higher success rates with prophylactic NIV (81%) compared with non-prophylactic use (50%; p=0.037). This may explain why no statistically significant association was found between the STAT Mortality Score and NIV failure in our results.

Furthermore, the odds ratios observed in our study (1.01 for mechanical ventilation duration and ICU stay, and 1.06 for NIV duration) indicate very weak positive associations. These values suggest only minimal increases in failure probability with longer support times, and their clinical impact is likely negligible. Nevertheless, these parameters highlight the need for careful monitoring of NIV duration and patient response. As emphasized by Ódena et al.[16] and Rolim et al.,[38] prolonged NIV without improvement should prompt reevaluation and timely reintubation, as extended ineffective support may worsen outcomes.

Limitations

The small sample size (n=110) limits the statistical power of the study and may explain the lack of significant associations despite clinically relevant trends. This limitation, along with the retrospective single-center design, introduces potential biases such as incomplete data and institutional practice variations. Additionally, NIV outcomes can depend heavily on the clinical experience of the multidisciplinary team and individual patient comorbidities.

Despite these limitations, this study contributes to the understanding of postoperative respiratory management in pediatric CHD patients by demonstrating that the STAT Mortality Score—though not directly associated with NIV failure—may still help identify patients at higher risk who could benefit from prophylactic NIV and closer monitoring.

Conclusion

Higher-risk STAT categories are typically associated with greater surgical complexity and potentially higher mortality. However, in this study, no statistically significant association was found between the STAT Mortality Score and Categories and NIV failure in children undergoing surgery for congenital heart disease.

Although mechanical ventilation duration, NIV duration, and ICU length of stay showed odds ratios of 1.01 and 1.06, these values indicate very weak positive associations with minimal clinical relevance. Each additional day of NIV or mechanical ventilation slightly increased the likelihood of failure, but the effect was negligible.

Clinically, these findings highlight that NIV failure in this population is likely influenced more by individual postoperative factors—such as hemodynamic instability or low weight—than by the surgical risk classification itself.

Nonetheless, recognizing these subtle trends may support early identification of at-risk patients and guide decisions about prophylactic NIV use and postoperative monitoring.

Future multicenter prospective studies with larger samples are recommended to validate these results and further explore the predictive utility of STAT metrics as a complementary tool in postoperative respiratory management.

Ethics Committee Approval: Ethics committee approval was obtained from Ethics Committee of National Institute of Cardiology (Approval Number: 68156623.5.0000.5272, Date: 31.03.2023).

Informed Consent: Written informed consent was not required due to the retrospective nature of this study.

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