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Epidemiology of Noninvasive Ventilation in Pediatric Cardiac Intensive Care Units

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Abstract

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Objective—To describe the epidemiology of noninvasive ventilation (NIV) therapy for patients admitted to pediatric cardiac intensive care units (CICU), and to assess practice variation across hospitals.

Design—Retrospective cohort study using prospectively collected clinical registry data.

Setting—Pediatric Cardiac Critical Care Consortium (PC4) clinical registry.

Patients—Patients admitted to CICUs at PC4 hospitals.

Interventions—None.

Measurements and Main Results—We analyzed all CICU encounters that included any respiratory support from 10/2013-12/2015. NIV therapy included high flow nasal cannula (HFNC) and positive airway pressure (PAP) support. We compared patient and, when relevant, perioperative characteristics of those receiving NIV to all others. Subgroup analysis was performed on neonates and infants undergoing major cardiovascular surgery. To examine duration of respiratory support we created a casemix-adjustment model and calculated adjusted mean durations of total respiratory support (MV + NIV), MV, and NIV. We compared adjusted duration of support across hospitals. The cohort included 8,940 encounters from 15 hospitals: 3,950 (44%) received NIV, 72% were neonates and infants. Medical encounters were more likely to include NIV than surgical. In surgical neonates and infants, 2,032 (55%) received postoperative NIV. Neonates, extracardiac anomalies, single ventricle, procedure complexity, preoperative respiratory support, MV duration, and postoperative disease severity were associated with NIV therapy ($p < 0.001$ for all). Across hospitals, NIV use ranged from 32%-65%, and adjusted mean NIV duration ranged from 1-4 days (3 days observed mean). Duration of total adjusted respiratory support was more strongly correlated with duration of MV compared to NIV (Pearson's $r = 0.93$ vs 0.71 , respectively).

Conclusions—NIV use is common in CICUs, especially in patients admitted for medical conditions, infants, and those undergoing high complexity surgery. We observed wide variation in NIV use across hospitals, though the primary driver of total respiratory support time seems to be duration of MV.

Keywords

Noninvasive ventilation; Heart defects; congenital; registries; cardiac surgical procedures

Introduction

Pediatric cardiac intensive care units (CICU) increasingly use noninvasive ventilation (NIV) therapies to support respiration in children with critical cardiovascular disease. Previous single-center studies demonstrate the safety and effectiveness of NIV in the management of respiratory insufficiency in infants and children [1-3], including those undergoing cardiac surgery [4-8]. NIV therapy may hold promise to decrease ICU length of stay, complications associated with invasive respiratory support, and improve other clinical outcomes for patients in the CICU by allowing reduction in mechanical ventilation (MV). Others hypothesize that increasing use of NIV therapy may paradoxically prolong the critical care period.

Many questions exist regarding NIV therapy in the current era within pediatric CICUs. The basic clinical epidemiology of NIV utilization - which patients receive NIV, typical duration of therapy, and use of specific types of NIV therapies - has never been studied in a large cohort of critically ill children with cardiovascular disease. Furthermore, as most of the existing data come from single center studies [4-8], very little is known about how use may vary across hospitals. Finally, the relative contribution from NIV and MV to the total respiratory support time of patients in the CICU remains unknown. Filling these knowledge gaps would help to frame the important areas of future study in order to understand best practices for utilizing NIV and to inform quality improvement initiatives aimed at optimizing respiratory support of children in the CICU.

In this context, we performed an analysis from the Pediatric Cardiac Critical Care Consortium (PC4) clinical registry to describe the clinical epidemiology of NIV use in a contemporary, multicenter cohort of patients treated in pediatric CICUs. We sought to describe the clinical characteristics of all patients receiving NIV in the CICU and the frequency, modes, and duration of NIV therapy. We then focused on a more homogenous group of patients – neonates and infants undergoing cardiac surgery – in order to explore variation in NIV use across PC4 hospitals and how NIV impacts differences between centers in duration of total respiratory support.

Materials and Methods

Data infrastructure

PC4 is a quality improvement collaborative consisting of hospitals from North America who participate voluntarily [9]. Data from all CICU encounters are submitted to the clinical registry; at the time of this data analysis 15 hospitals were submitting cases. The registry variables include patient demographics, CICU encounter characteristics, surgical data, critical care practices, and outcomes. Trained data managers who pass an annual certification exam enter data into the registry. All data fields are defined according to standardized definitions in a data definitions manual that is available to all participants on the PC4 internal website. The PC4 Data Coordinating Center audits every participating center on a regular schedule using a combined method of blind chart abstraction by auditors and source data verification [9]. Cases cannot be submitted to the registry unless all mandatory data fields are complete, and approximately 90% of fields are required for submission. Participation in PC4 is considered quality improvement by the institutional review board (IRB) at the University of Michigan data coordinating center. Specific approval for this project was obtained and the IRB waived the need for written informed consent for the study. Data used for the study were de-identified prior to analysis.

Inclusion and exclusion criteria

We analyzed all CICU encounters involving respiratory support from 10/2013 – 12/2015. This included encounters initiated in the operating room. It was assumed that all patients who underwent cardiothoracic surgery were intubated and mechanically ventilated during the procedure. All encounters from a hospitalization were analyzed separately.

We excluded records with missing MV and/or NIV start/end dates. Data quality check showed very few records were missing (22 encounters without NIV start/end dates). There were 31 records where airway anomaly information was missing. Patients who had a tracheostomy at the beginning of the CICU encounter and those who died or were made DNR prior to any planned extubation attempt were also excluded from the analysis.

Data Collection

Data variables from the registry specific to the study include the date of initiation and end of each MV and NIV episode. The mode of NIV therapy - positive airway pressure [PAP, including continuous positive airway pressure (CPAP) and bi-level positive airway pressure (BiPAP)] or high flow nasal cannula (HFNC) – is recorded daily. The specific time of NIV therapy is not recorded; any use of the therapy on a calendar day was considered as one day of use in the analysis. Though the database contains exact start and stop times of MV, we chose to use a similar data structure. When patients received MV and NIV on the same day we recorded half-day use of each support type. Duration of MV was restricted to MV during the CICU encounter only; respiratory support received at outside hospitals for patients transferred to participating CICUs was excluded. Patients receiving MV in the cardiothoracic operating room only (e.g. patients extubated on arrival to the CICU) were grouped in the MV-only category with a duration of MV of zero minutes unless they were later on mechanically ventilated in the CICU encounter.

Patient, encounter, preoperative, operative, and postoperative clinical variables were collected for encounter level analysis. PC4 data entry for surgical variables is harmonized with data collection for the Society of Thoracic Surgery (STS) Congenital Heart Surgery Database at the participating hospitals as previously described (7). Weight-for-age z-score was calculated using World Health Organization or Centers for Disease Control standards, according to patient age [10] for children and body mass index (BMI) for adults. Airway anomalies and additional extracardiac anomalies were recorded according to the International Paediatric and Congenital Cardiac Code (IPCCC) [11]. A patient was classified as having an airway anomaly if they had any of the following [12]: major abnormality of the larynx-trachea-bronchus, congenital tracheal stenosis, laryngomalacia, tracheomalacia, bronchomalacia, or other major abnormality of the larynx-trachea-bronchus. Newly acquired diaphragm paralysis and vocal cord dysfunction were recorded and included in the analyses. A surgical encounter was defined as any that included a Society of Thoracic Surgeons index operation immediately before or during the encounter: operations with cardiopulmonary bypass or cardiovascular surgery without bypass, exclusive of patients <2.5kg undergoing isolated patent ductus arteriosus repair or undergoing operations that could not be classified into one of the Society of Thoracic Surgeons-European Association for Cardiothoracic Surgery (STAT) mortality categories [13]. Medical encounters were those that did not include an index operation. The Society of Thoracic Surgeons-European Association for Cardiothoracic Surgery (STAT) mortality categories were used to classify surgical complexity [13]. ICU length of stay was defined as admission date through critical care end date.

Statistical Analysis

Entire cohort—We first analyzed all CICU encounters involving respiratory support to describe the frequency and characteristics of encounters in which NIV therapy was delivered. In an encounter-level analysis, we compared encounters with NIV only, MV and NIV, or MV only, using the Kruskal-Wallis test for continuous variables and chi-square or Fisher Exact test for categorical data as appropriate. We report these data stratified by surgical vs. medical encounters. Univariate comparisons between encounters where NIV was used vs. those where NIV was not used were performed using the Wilcoxon rank sum test for continuous variables, and chi-square or Fisher exact test for categorical data as appropriate. Descriptive data are presented as median (interquartile range) for continuous variables and frequency (percentage) for categorical variables.

Surgical neonate and infant subgroup—We then performed an analysis of NIV therapy within the subgroup of neonates and infants (<1 year old) undergoing index cardiovascular surgical procedures. This subpopulation allows a more meaningful exploration of variation in NIV use between hospitals as it minimizes casemix differences and well-described patient and operative variables can be used for further casemix-adjustment. We restricted our analysis to the index surgical CICU encounter (i.e. readmissions during the same hospitalization were excluded) to allow the analysis to evaluate a more homogenous patient population to better evaluate practices across hospitals. We again compared factors between encounters with NIV use vs. those with no NIV as above. Univariate comparisons were performed using the Wilcoxon rank sum for continuous variables and chi-square or Fisher exact test for categorical data.

Next, we calculated casemix-adjusted (observed-to-expected) duration of total respiratory support, MV, and NIV for each hospital using a zero-inflated negative binomial regression model. This model included patient factors associated with duration of ventilation previously derived from the PC4 registry [14]: age, non-cardiac chromosomal or structural anomalies, prematurity, weight-for-age z-score, STAT category, and preoperative MV. The model was used to generate an expected duration of ventilation for each patient. We present the casemix-adjusted mean duration of total respiratory support, MV, and NIV by hospital; median durations were not reported as there is no accepted method to calculate an adjusted median value. Pearson's r was used to assess the correlation between duration of total respiratory support and duration of MV and NIV, respectively.

Finally, we sought to understand outcomes in encounters where prolonged NIV therapy was administered. We defined prolonged therapy as at least 3 or more consecutive days of NIV therapy. We identified all encounters meeting this inclusion criteria, and then summed the total days of NIV therapy until CICU discharge or reaching any one of four mutually exclusive endpoints: reintubation, tracheostomy, cardiac reintervention, or death. A Kaplan-Meier curve was plotted to show event-free survival to CICU discharge. Analyses were performed using SAS Version 9.4 (SAS Institute, Cary, NC) or STATA Version 14 (Stata Corp, College Station, TX), with statistical significance at a p -value of less than 0.05.

Results

Epidemiology of noninvasive ventilation therapy – all patients

A total of 7,396 hospitalizations and 8,940 CICU encounters from 15 hospitals met inclusion criteria and formed the analytic cohort. There were 7,314 encounters that included an index cardiothoracic operation; of these, 72% (n=5,244) received postoperative respiratory support. Among all encounters, 44% (n=3,950) included NIV therapy in the CICU. Neonates and infants comprised 54% (n=4850) of the total cohort and 72% (n=2,842) of those who received NIV. Tables 1 and 2 display characteristics of surgical and medical encounters, respectively. Encounters for pre-operative management were more likely to include NIV than strictly post-operative cardiothoracic surgery or medical encounters; 76% (n=942), 44% (n=1,497), and 67% (n=1,088), respectively.

Table 3 displays outcomes of encounters that included respiratory support in the CICU. Encounters where both MV and NIV were used demonstrated longer duration of respiratory support in both cohorts. HFNC use was more common than PAP support for patients who only received NIV and for those who received NIV in combination with MV.

Respiratory support in surgical neonates and infants

A total of 3,708 neonates and infants had encounters which included an index cardiothoracic operation. Of these, 55% (n=2,032) received postoperative NIV; 72% (n=1,063) of neonates and 43% (n=969) of infants. Table 4 shows the characteristics of this cohort. Supplemental table 1 (Supplemental digital content) shows clinical outcomes for those neonates and infants who received NIV postoperatively. Compared to infants, neonates had longer duration of total respiratory support, ICU length of stay, hospital length of stay, increased risk of an unplanned reintervention, and increased mortality compared with infants. Of those neonates and infants receiving NIV only, 7% (n=151) received PAP only, 57% (n=1153) received HFNC only, and 36% (n=728) received PAP and HFNC. The observed median duration of total respiratory support was 3 days (IQR 2-7) for the entire cohort, 1 day (IQR 0-2) for patients receiving MV only, and 6 days (IQR 3-11) for those receiving NIV.

Factors associated with postoperative NIV in neonates and infants—Patient characteristics associated with receipt of NIV on univariate analysis ($p < 0.001$) are shown in Table 4. Multivariable logistic regression revealed neonatal age group, presence of extracardiac and airway anomalies, higher STAT category, receipt of preoperative respiratory support, longer postoperative mechanical ventilation (MV) time, and greater postoperative disease severity (defined as receipt of vasoactive support, paralyzed diaphragm, vocal cord dysfunction, and major postoperative complication) were independently associated with receipt of postoperative NIV (all $p < 0.001$).

Hospital variation in NIV use—Across hospitals, NIV use for neonates and infants ranged from 32%-65%. The unadjusted mean duration of total postoperative respiratory support time ranged from 4-10 days, mean MV duration 3-6 days, and mean NIV duration 1-4 days across hospitals. Adjusted mean duration for each mode of respiratory support at each hospital is shown in Figure 1. The adjusted mean duration of respiratory support ranged

from 4-11 days, mean MV duration 3-7 days, and mean NIV duration 2-4 days across hospitals. Duration of total adjusted respiratory support was more strongly correlated with duration of MV compared to NIV (Pearson's $r=0.93$ vs 0.71 , respectively).

Prolonged NIV use—To determine the clinical outcomes of surgical neonates and infants receiving prolonged postoperative NIV therapy, we examined all surgical neonates and infants who received NIV for at least 3 consecutive postoperative days. A total of 1,200 encounters met inclusion criteria. Figure 2 shows Kaplan-Meier curves for time to reintubation, reoperation, tracheostomy, or death based on the total number of postoperative NIV days. There was 75% event-free survival after 8 total days of NIV therapy, 50% at 16 days, and 25% at 25 days. The most common event was reintubation. Of the 1,200 encounters, there were 201 reintubations; 75% intubation-free survival at 10 days, 50% at 18 days, and 25% at 32 days.

Discussion

Previous single center studies have shown NIV to be an effective mode of respiratory support in the management of children with heart disease [6], including following cardiac surgery [4, 7, 8]. Our study represents the most comprehensive description to-date of NIV therapy in contemporary pediatric cardiac critical care, and the first to assess NIV therapy in a multi-institutional cohort. This analysis provides important data on what has now become a common practice in CICUs; of all patients who receive respiratory support, over half receive NIV, regardless of whether that patient is admitted to the CICU for treatment of medical or surgical indications. We identified several patient and encounter variables associated with receipt of NIV therapy in the subgroup of surgical neonates and infants. Finally, we described the relative contributions of mechanical ventilation and NIV to total duration of respiratory support using a casemix-adjustment model in neonates and infants undergoing cardiac surgery.

Perhaps not surprisingly, we found younger age, presence of extracardiac anomalies, surgical complexity, and greater disease severity were associated with receipt of NIV in both medical and surgical encounters. Previous literature provides little insight into these factors, though these prior reports do include a majority of infants and patients with higher complexity surgical procedures [7, 8]. It is unclear what drives greater delivery of NIV therapies in the high-use subgroups we identified. These patients certainly have many reasons for more complex cardiopulmonary pathophysiology and more organ dysfunction, thus requiring prolonged assistance for adequate oxygenation and ventilation. However, it is also possible that clinicians have a bias to provide more respiratory support to these higher-risk patients regardless of subjective or objective measures of respiratory function. This question of whether NIV therapy is “necessary” should receive attention subsequent to our analysis. While appropriate NIV therapy may prevent respiratory failure, cardiac arrest, or other major complications, unnecessary NIV therapy could prolong the critical care period and exposure to invasive devices and medications that can potentially harm patients.

We observed significant variation in NIV use across hospitals in the care of surgical infants, with rates ranging from 32-65% and adjusted duration of NIV therapy from 1-4 days.

Though both adjusted MV and NIV durations were strongly correlated with duration of total respiratory support, this was even more true for MV and the absolute difference in MV days between hospitals at opposite ends of the continuum was much greater. Based on our findings, we believe that efforts to identify practices of hospitals with the lowest adjusted duration of mechanical ventilation are likely to have the greatest impact on decreasing the duration of total respiratory support and potentially ICU length of stay. Strategies to effectively and selectively apply NIV therapy may be a feature of high-quality respiratory care hospitals. It remains unknown how hospitals use NIV during periextubation periods (e.g. planned at time of extubation vs. rescue therapy), or as treatment for impending respiratory failure. A previously published study aimed to identify predictors of success of NIV in preventing extubation failure, though the retrospective nature of the study makes it challenging to draw conclusions in how NIV can best be used to prevent extubation failure [7]. The impact of different NIV strategies on reintubation rates remains a major outstanding question, and future trials are warranted based on our understanding of variation in extubation failure across hospitals [15, 16].

The analysis of patients receiving prolonged NIV therapy (at least 3 consecutive days) suggests that these patients are at high risk for adverse outcomes. While this is somewhat intuitive, these data may help clinicians quantify the risk for particular events when caring for patients who cannot wean from NIV therapy. The most important missing pieces of information to fully understand and predict the risk of events in patients unable to wean from NIV include knowledge of residual cardiac lesions, compromised ventricular function, and/or airway, vocal cord, or diaphragm injuries. Unfortunately, the PC4 registry does not include some of these data in sufficient detail to explore these more complex associations. This is an area ripe for future investigation, and increasing our ability to predict the adverse outcomes we studied here among patients receiving prolonged respiratory support could have a direct and substantial impact on clinical care.

The typical limitations associated with analyzing observational data from a clinical registry apply to our study. The PC4 registry does not contain all variables that may impact outcomes assessment through confounding or other mechanisms. As previously mentioned, we could not assess the intention of the treating clinician when administering NIV therapy, thus limiting our understanding of practice variation across hospitals. The relatively small number of hospitals precluded analysis of hospital characteristics that might impact hospital-level respiratory duration outcomes using a hierarchical regression approach. Airway anomalies influence duration of respiratory support, and there is likely practice variation between hospitals in evaluating the airways (e.g. routine use of bronchoscopy following extubation failure) postoperatively. This represents one form of ascertainment bias that may be present in our dataset. In our analysis of surgical neonates and infants, those extubated in the operating room had a MV time of 0 days, whereas those extubated early in the CICU were classified as having 1 day of MV. By choosing this data structure, we may be slightly overestimating MV time at hospitals that do not routinely extubate patients in the operating room. However, previous analysis of the PC4 database shows that most hospitals are performing extubation in the OR between 25-50% of all cases [*Note to editorial staff, this paper is currently in final revision at another journal. We will insert the reference at the time of publication of this manuscript*]. Finally, we chose to include HFNC as a NIV therapy.

There is a healthy debate amongst clinicians about whether HFNC is truly “ventilatory” support, but we chose to include this therapy since it does impact critical care duration at many institutions. Further, as a newer therapy in the CICU armamentarium we felt it was important to characterize current use of HFNC in this multi-institutional cohort.

Conclusions

Our analysis shows that NIV use is common in contemporary CICU practice, and varies considerably. Our study illuminates differences in respiratory practices and outcomes across hospitals, but these data cannot yet provide actionable information to alter clinical practice. As such, it is imperative to move beyond epidemiologic description and gain a deeper understanding of how NIV therapies can be optimally applied to improve clinical outcomes for patients with critical cardiovascular disease. Future quality improvement efforts to reduce duration of respiratory support and CICU length of stay will likely focus on safely limiting mechanical ventilation, and NIV therapy may be an important adjunctive strategy to safely transition patients off of mechanical ventilation. Collaborative learning approaches among hospitals, highlighting and disseminating the practices of those hospitals with the best respiratory support outcomes, are likely to yield the greatest gains for these children.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.

Adjusted mean duration of respiratory support by hospital. The black bars represent the total adjusted duration of respiratory support, the dark gray bars represent the adjusted duration of MV, and the light gray bars represent the adjusted duration of NIV. All durations are in days.

Figure 2.

Kaplan-Meier curve showing freedom from reintubation, reoperation, tracheostomy, death, and any combination of these outcomes based on the total days of postoperative NIV therapy. NIV = noninvasive ventilation. CICU = cardiac ICU.

Table 1
Characteristics of Cardiac Intensive Care Unit Surgical Encounters Including Respiratory Support

Patient characteristics	Total N=5,244	Type of Respiratory Support Received		p
		NIV only N=367	NIV + MV N=2,495	
Male	2,918	198 (6.8%)	1,406 (48.2%)	1,314 (45%)
Weight for age z-score				0.64
z> -2	3,907	279 (7.1%)	1,782 (45.6%)	1,846 (47.2%)
z< -2	1,337	88 (6.6%)	713 (53.3%)	536 (40.1%)
Age group				<.0001*
Neonate	1,519	51 (3.4%)	1,129 (74.3%)	339 (22.3%)
Infant	1,866	140 (7.5%)	883 (47.3%)	843 (45.2%)
Child	1,623	161 (9.9%)	418 (25.8%)	1,044 (64.3%)
Adult	236	15 (6.4%)	65 (27.5)	156 (66.1%)
Extracardiac Anomalies	670	50 (7.5%)	365 (54.5%)	255 (38.1%)
Airway anomaly	228	12 (5.3%)	148 (64.9%)	28 (29.8%)
Chromosomal/Genetic	1,018	86 (8.4%)	545 (53.5%)	387 (38%)
Syndrome	1,111	97 (8.7%)	580 (52.2%)	434 (39.1%)
Encounter characteristics				
Initial reason for CICU admission				<.0001*
Pre-op cardiothoracic surgery	1,240	43 (3.5%)	899 (72.5%)	298 (24%)
Post-op cardiothoracic surgery	3,422	309 (9%)	1188 (34.7%)	1925 (56.3%)
Post cardiac catheterization	60	1 (1.7%)	34 (56.7%)	25 (41.7)
Post-op non-cardiothoracic surgery	11	2 (18.2%)	6 (54.5%)	3 (27.3%)
Medical condition	343	11 (3.2%)	238 (69.4%)	94 (27.4%)
Evaluation of structural heart disease	168	1 (0.6%)	130 (77.4%)	37 (22%)
Intervention(s) immediately before/during the encounter				
CPB/non-CPB surgery	5,128	359 (7%)	2445 (47.7%)	2,324 (45.3%)
Other cardiothoracic surgery	428	11 (2.6%)	275 (64.3%)	142 (33.2%)
Cardiac catheterization (including diagnostic cath)	735	29 (3.9%)	540 (73.5%)	166 (22.6%)
Mechanical circulatory support during this encounter	360	0	227 (63.1%)	133 (36.9%)
Any vasoactive support during this encounter	4,645	276 (5.9%)	2,342 (50.4%)	2,027 (43.6%)

	Type of Respiratory Support Received			<i>p</i>
	Total N=5,244	NIV only N=367	NIV + MV N=2,495	MV only N=2,382
Any continuous sedation/neuromuscular block during this encounter	4,728	294 (6.2%)	2,336 (49.4%)	2,098 (44.4%)
Sternum left open	665	0	519 (78%)	146 (22%)
Inhaled nitric oxide during this encounter	963	30 (3.1%)	723 (75.1%)	210 (21.8%)
Unplanned reoperation or reintervention	543	15 (2.8%)	379 (69.8%)	149 (27.4%)
				<.0001

NIV, Noninvasive ventilation; MV, Mechanical ventilation; CICU, Cardiac ICU

Data is presented as n (%).

Table 2
Characteristics of Cardiac Intensive Care Unit Medical Encounters Including Respiratory Support

Patient characteristics	Total N=1,626	Type of Respiratory Support Received			p
		NIV only N=608	NIV + MV N=480	MV only N=538	
Male	891	331 (37.1%)	260 (29.2%)	300 (33.7%)	0.86
Weight for age z-score					0.73
z> -2	1,113	414 (37.2%)	324 (29.1%)	375 (33.7%)	
z< -2	513	194 (37.8%)	156 (30.4%)	163 (31.8%)	
Age group					<.0001*
Neonate	458	110 (24%)	163 (35.6%)	185 (40.4%)	
Infant	515	200 (38.8%)	166 (32.2%)	149 (28.9%)	
Child	528	241 (45.6%)	129 (24.4%)	158 (29.9%)	
Adult	125	57 (45.6%)	22 (17.6%)	46 (36.8%)	
Extracardiac Anomalies	669	263 (39.3%)	200 (29.9%)	206 (30.8%)	0.0711
Airway anomaly	120	50 (41.7%)	42 (35%)	28(23.3%)	0.06
Chromosomal/Genetic	1,018	86 (8.4%)	545 (53.5%)	387 (38%)	<.0001
Syndrome	1,111	97 (8.7%)	580 (52.2%)	434 (39.1%)	<.0001
Encounter characteristics					<.0001*
Initial reason for CICU admission					
Pre-op cardiothoracic surgery	86	16 (18.6%)	30 (34.9%)	40 (46.5%)	
Post-op cardiothoracic surgery	10	0 (0%)	2 (20%)	8 (80%)	
Post cardiac catheterization	261	46 (17.6%)	67 (25.7%)	148 (56.7%)	
Post-op non-cardiothoracic surgery	111	18 (16.2%)	38 (34.2%)	55 (49.5%)	
Medical condition	1,038	497 (47.9%)	302 (29.1%)	239 (23%)	
Evaluation of structural heart disease	120	31 (25.8%)	41 (34.2%)	48 (40%)	
Cardiac catheterization immediately before/during the encounter	520	85 (16.3%)	214 (41.2%)	221 (42.5%)	<.0001
Mechanical circulatory support during this encounter	26	3 (11.5%)	8 (30.8%)	15 (57.7%)	0.008
Any vasoactive support during this encounter	609	110 (18.1%)	273 (44.8%)	226 (37.1%)	<.0001
Any continuous sedation/ neuromuscular block during this encounter	702	46 (6.6%)	362(51.6%)	294(41.9%)	<.0001
Sternum left open	2	1 (50%)	1 (50%)	-	0.22
Inhaled nitric oxide during this encounter	202	42 (20.8%)	109 (54%)	51 (25.2%)	<.0001

	Type of Respiratory Support Received				<i>p</i>
	Total N=1,626	NIV only N=608	NIV + MV N=480	MV only N=538	
Unplanned reoperation or reintervention	16	2 (12.5%)	10 (62.5%)	4 (25%)	0.01

NIV, Noninvasive ventilation; MV, Mechanical ventilation; CICU, Cardiac ICU

Data is presented as n (%).

Table 3
Outcomes of Patients Receiving Respiratory Support in the Cardiac Intensive Care Unit

Outcomes	Surgical			Medical		
	NIV only N=367	NIV + MV N=2,495	MV only N=2,382	NIV only N=608	NIV + MV N=480	MV only N=538
Type of NIV therapy received						
CPAP/BiPAP	53 (14.4%)	196 (7.9%)	-	118 (19.4%)	69 (14.4%)	-
HFNC	211 (57.5%)	1,427 (57.2%)	-	393 (64.6%)	275 (57.3%)	-
Both	103 (28.1%)	872 (34.9%)	-	97 (16.1%)	136 (28.3%)	-
Duration of Respiratory support (days)						
NIV	2 (2-4)	3 (2-7)	N/A	3 (2-4)	3 (2-6)	N/A
MV	N/A	4 (2-9)	2 (1-2)	N/A	4 (2-7)	2 (1-4)
Total	2 (2-4)	7 (4-15)	2 (1-2)	3 (2-4)	7 (4-12)	2 (1-4)
Unplanned reoperation/reintervention	15 (4.1%)	379 (15.2%)	149 (6.3%)	N/A	N/A	N/A
Bronchoscopy performed	51 (13.9%)	180 (7.2%)	51 (2.1%)	17 (2.8%)	68 (14.2%)	31 (5.8%)
Mortality	0 (0%)	90 (3.6%)	132 (5.5%)	13 (2.1%)	55 (11.5%)	74 (13.8%)

NIV, Noninvasive ventilation; MV, Mechanical ventilation; CPAP, Continuous positive airway pressure; BiPAP, Bi-level positive airway pressure

Data is presented as n (%) or median (interquartile range) as appropriate.

Table 4
Characteristics of Surgical Neonates and Infants

	Total N = 3,708	NIV postoperatively N=2,032	No NIV postoperatively N=1,676	P-Value
Patient Characteristics				
Male	2,043	1,134 (55.5%)	909 (44.5%)	0.35
Weight group at hospital admission				0.99
Not underweight	1,221	669 (54.8%)	552 (45.2%)	
Underweight	2,487	1,363 (54.8%)	1,124 (45.2%)	
Age group at hospital admission				<.0001*
Neonate	1,477	1,063 (72%)	414 (28%)	
Infant	2,231	969 (43.4%)	1,262 (56.6%)	
Extracardiac/Chromosomal/Genetic/Syndrome Anomalies (no airway anomaly)	1,190	723 (60.8%)	467 (39.2%)	<.0001
Airway anomaly	170	111 (65.3%)	59 (34.7%)	
Reason for CICU admission				<.0001*
Pre-op cardiothoracic surgery	1,168	833 (71.3%)	335 (28.7%)	
Post-op cardiothoracic surgery	2,150	926 (43.1%)	1,224 (56.9%)	
Other	390	273 (70%)	117 (30%)	
STAT category for index operation				<.0001*
STAT category 1	778	281 (36.1%)	497 (63.9%)	
STAT category 2	1,016	449 (44.2%)	567 (55.8%)	
STAT category 3	597	374 (62.6%)	223 (37.4%)	
STAT category 4	1,035	703 (67.9%)	332 (32.1%)	
STAT category 5	282	225 (79.8%)	57 (20.2%)	
CPB at index operation	3,028	1,686 (55.7%)	1,342 (44.3%)	0.023
Aortic cross-clamp at index operation	2,863	1,577 (55.1%)	1,286 (44.9%)	0.53
Preoperative respiratory support in the CICU	898	690 (76.8%)	208 (23.2%)	<.0001
NIV	431	359 (83.3%)	72 (16.7%)	<.0001
Mechanical vent	695	515 (74.1%)	180 (25.9%)	<.0001
Postoperative vasoactive support	3,237	1,880 (58.1%)	1,357 (41.9%)	<.0001
Postoperative diagnosis of paralyzed diaphragm	50	47 (94%)	3 (6%)	<.0001
Postoperative diagnosis of vocal cord dysfunction	122	101 (82.8%)	21 (17.2%)	<.0001
Major postoperative complication	807	567 (70.3%)	240 (29.7%)	<.0001

CICU, Cardiac intensive care unit; STAT, Society of Thoracic Surgeons-European Association for Cardiothoracic Surgery; CPB, Cardiopulmonary bypass

Data is presented as n (%).