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Center Variation in Chest Tube Duration and Length of Stay After Congenital Heart Surgery

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Abstract

Background: Nearly every child undergoing congenital heart surgery has chest tubes (CT) placed intraoperatively. Center variation in removal practices and impact on outcomes has not been

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studied previously. We evaluated variation in CT management practices and outcomes across centers.

Methods: We included patients undergoing any of 10 benchmark operations from June 2017-May 2018 at participating Pediatric Acute Care Cardiology Collaborative (PAC^3)- Pediatric Cardiac Critical Care Consortium (PC^4) centers. Clinical data from PC^4 were merged with CT data from PAC^3. Practices and outcomes were compared across centers in univariate and multivariable analysis.

Results: The cohort included 1029 patients (N=9 centers). Median CT duration varied significantly across centers for 9/10 benchmark operations (all p≤ 0.03) with a “model” center noted to have the shortest duration for 9/10 operations (range of 27.9–87.4% shorter duration vs. other centers across operations). This effect persisted in multivariable analysis (p<0.0001). The model center had higher volumes of CT output prior to removal [median 8.5 (model) vs 2.2 (other centers) cc/kg/24 hours, p <0.001], but did not have higher rates of CT reinsertion (model center 1.3% vs. 2.1%, p = 0.59) or readmission for pleural effusion (model center 4.4% vs. 3.0%, p = 0.31), and had the shortest LOS for 7/10 operations.

Conclusions: This study suggests significant center variation in CT removal practices and associated outcomes after congenital heart surgery. Best practices utilized at the model center have informed the design of an ongoing collaborative learning project aimed at reducing CT duration and LOS.

Classifications

Congenital Heart Disease; CHD

Introduction

As mortality following surgery for congenital heart disease has declined, increasing attention has been paid to reducing perioperative morbidity. One previously unexplored potential contributor to perioperative morbidity is chest tube duration. Nearly every child undergoing congenital heart surgery has chest tubes placed intraoperatively. The presence of a chest tube may impact patients’ need for analgesia and sedation, readiness to ambulate, risk of infection, and postoperative length of stay (LOS).

Despite the ubiquity of chest tubes in the congenital heart surgery population, management practices and outcomes related to chest tube duration have not been previously described. [1,2] Taylor et al. recently reported significant variation in centers’ self-reported approaches to chest tube management, including volume criteria for removal, use of chest radiographs, and discharge timing related to removal.[2] It remains unclear whether this self-reported variation in management practices is associated with actual variation in chest tube duration, need for chest tube replacement, or LOS.

The purpose of this study was to evaluate variation in chest tube management practices and outcomes across centers. We hypothesized that there would be variation in chest tube management practices associated with differences in chest tube duration. Our goal was to identify potential best practices for chest tube management to subsequently inform a multicenter quality improvement (QI) project to reduce variation in chest tube duration and improve associated outcomes.

Methods

This study was approved by the Cincinnati Children's Hospital Medical Center Institutional Review Board. A waiver of consent was granted.

Data Sources

Data from the Pediatric Cardiac Critical Care Consortium (PC^4) and the Pediatric Acute Care Cardiology Collaborative (PAC^3) were used for this study. The aim of PC^4 is to improve the quality of care delivered in the pediatric cardiac intensive care unit. The PC^4 registry shares common terminology and definitions with applicable data points with The Society of Thoracic Surgeons Congenital Heart Surgery Database.[3] The focus of PAC^3 is quality improvement and research related to the acute care cardiology ward, defined as a hospital unit focused on caring for children with heart disease who do not require intensive care.[4]

Integration between PC^4 and PAC^3 was facilitated by Cardiac Networks United,[5] an organization which supports integration of pediatric cardiovascular data and collaboration across networks to facilitate research and improvement. Data were linked using a common patient identifier and confirmed with operation type and date of procedure. PC^4 data included baseline demographic information, diagnosis and operation type, perioperative information, and postoperative LOS. Postoperative LOS was defined as the time from date of surgery to date of discharge from the study center. PAC^3 captured variables specific to chest tube management, including chest tube duration, volume of output prior to removal (adjusted for weight), need for chest tube replacement during index hospitalization, and readmission due to pleural effusion within 7 days of discharge. The most recent blood urea nitrogen and creatinine levels prior to chest tube removal were collected as markers of hydration status at the time the decision to remove the chest tube would have been made.

Study population

All centers participating in both PAC^3 and PC^4 were invited to join the study. All patients who underwent one of the 10 benchmark operations defined by the Society of Thoracic Surgery[6,7] between June 2017 and May 2018 were eligible for inclusion. Patients with hemothorax, chylothorax, a second cardiothoracic operation during the same admission, or who died prior to hospital discharge were excluded as their management or outcomes would differ due to those conditions. We recorded the prevalence of hemothorax and chylothorax for all patients who underwent benchmark operations during the study period since variability in diagnostic criteria across centers might impact the study population.

Outcomes

The primary outcome was median chest tube duration in hours. This was calculated as the difference between the time of postoperative cardiac intensive care unit admission and the time when the final perioperative chest tube was removed. We defined perioperative chest tubes as all chest tubes placed during surgery (intraoperative) or while the original chest tubes from surgery were still in place (postoperative). Secondary outcomes were frequency of chest tube replacement after the final perioperative chest tube was removed, total postoperative LOS, and hospital readmissions within 7 days due to effusion.

Statistical Analysis

Categorical variables were summarized as frequency (percentage) and compared using Chi-square or Fisher Exact Chi-square test across centers. Continuous variables were summarized as median (interquartile range) or 10% trimmed means as an alternative measure of central tendency, and compared using Kruskal–Wallis test. Data from one “model” center which appeared to have different practices and outcomes were also compared to aggregate data from other centers. The relative difference in median duration at the model vs. other centers was calculated for each operation. In our assessment of baseline patient characteristics and severity of illness across centers, we considered several preoperative and intraoperative characteristics. Multivariable general linear regression was used to evaluate the primary outcome (chest tube duration with log-normal distribution) after adjusting for characteristics found to differ across centers in univariate analysis (Table 1). The final model included weight, operation type, and cardiopulmonary bypass duration (age was collinear with weight and not included). For all statistical tests, a p-value of less than 0.05 was considered statistically significant. Analyses were performed using SAS 9.4.

Results

Nine PAC^3-PC^4 centers agreed to participate, enrolling a total of 1029 patients distributed across the 10 benchmark procedures (Table 1).

Center Variation in Chest Tube Duration

When analyzed by operation type, there was significant variation across centers in median chest tube duration for 9 of 10 benchmark operations ($p \le 0.03$ for all), with the variation for the remaining operation (truncus arteriosus repair) approaching significance ($p = 0.05$) (Figure 1). Across all operations, one center consistently had a shorter chest tube duration, including the shortest duration in 9 of 10 procedures and 2nd shortest in the remaining procedure. When this center was compared to the other centers in aggregate, median chest tube duration at the model center was significantly shorter for all 10 benchmark operations ranging from 27.9 to 87.4% shorter across operations (Table 2).

Model Center Patient Characteristics

Patient preoperative and intraoperative characteristics at the model center were similar to those in the other centers for most variables examined (Table 1). There were a few differences with patients at the model center being younger, weighing less, having shorter duration of cardiopulmonary bypass and fewer delayed sternal closures (Table 1). The model center also performed higher complexity benchmark operations more frequently, for example the Norwood comprised 11.4% of model center’ operations vs. 7.6% of the other centers’ operations in aggregate.

When the overall rate of hemothorax was examined, the model center had zero instances versus 0.5% in the other sites combined (p = 0.59). For chylothorax, the model center had a rate of 1.9% vs. 5.9% at the other sites (p = 0.003).

Adjusted Chest Tube Duration

In multivariable analysis, accounting for the patient and operative characteristics shown to differ in the model center vs. others, chest tube duration remained significantly shorter at the model center (duration 2.1 times longer at other centers vs. model center, 95% CI 1.8–2.5, p<0.0001)

Model center Chest Tube Practices

In terms of specific chest tube management practices, the model center placed a lower median number of intraoperative chest tubes compared to other centers (Table 3). There was no difference in the rate of postoperative chest tube placement (Table 3). Notably, the model center had a higher volume of chest tube output in the 24 hours prior to removal as compared to the other centers (8.5 mL/kg vs 2.2 ml/kg, p <0.001). There was no difference in the blood urea nitrogen level prior to chest tube removal while creatinine values were slightly higher at the model center (0.39 vs 0.32, p <0.001).

Secondary Outcomes

There was no difference in rates of chest tube replacement (model center 1.3% vs. other centers 2.1%, p = 0.59; Table 3) or 7-day readmission for pleural effusion (model center 4.4% vs. other centers 3.0%, p = 0.31).

The model center had the shortest postoperative LOS for 7 of 10 procedures and was in the lowest tertile for LOS for 2 of the other 3 procedures (Figure 2). Of the total cohort, 96.5% (n=993) were discharged home, 2.2% (n=23) to another chronic care setting, and 1.3% (n=13) to another acute care setting.

Comment

We found significant variation in chest tube duration and associated management practices across centers, including the identification of one model center as a positive outlier. This model center removed chest tubes significantly earlier even after adjustment for important patient characteristics, without higher rates of replacement or readmission for pleural effusion, suggesting that earlier removal is safe and achievable. This model center consistently removed chest tubes with higher volumes of output in the preceding 24-hour period and without clinically meaningful differences in blood urea nitrogen or creatinine levels, indicating that their practice of earlier removal was not driven by a unique attainment of lower output volume. Additionally, and potentially related to their chest tube practice, the model center appeared to have shorter LOS than the other centers for multiple operation types.

We believe this is the first report of variation in chest tube duration and related management practices across congenital heart centers. Our findings are consistent with multiple prior reports which have documented substantial variation in other aspects of peri-operative care and outcomes in this population, including the use of intraoperative methylprednisolone, modified ultrafiltration, delayed sternal closure, and the location and duration of postoperative intensive care.[8–12] In terms of our primary outcome, in multivariable analysis we found that the model center had significantly shorter chest tube duration after adjustment for operation type, patient weight, and cardiopulmonary bypass time. As a result, the differences in patient characteristics we documented do not appear to explain the shorter chest tube duration at the model center. If anything, several of the characteristics identified would have predisposed the model center to have longer chest tube duration (e.g. more high complexity surgeries). In addition, the finding that the model center had the lowest rates of hemothorax and chylothorax indicates that the model center did not exclude patients from their cohort due to higher rates of these complications. Taken together, these findings suggest that other differences in practice at the model center are responsible, namely their practice of routinely removing chest tubes with higher output volumes compared to the other centers. Indeed, the data from our study confirm previously documented self-reported variation in chest tube management practices, such as volume criteria for removal, across PAC[3] centers.[2] Our finding that the model center has a shorter chest tube duration without higher rates of replacement or readmission suggests that there were not adverse events associated with earlier removal.

During the study period, ongoing discussions among centers identified that the model center had substantial differences in clinical decision making around chest tube removal after all operations except the Fontan. Most centers reported removing pleural tubes when the volume of output was below a specific threshold, regardless of the postoperative day. In contrast, the model center's approach was to generally remove chest tubes on the first postoperative day unless certain concerns were present. These concerns included the presence of sanguineous or chylous drainage, pneumothorax on chest xray, high volume of drainage in the preceding 8 hours, or other specific concern from the surgeon, such as thoracic duct injury or tissue edema in the operating room.

We also found that postoperative LOS was shorter at the model center, which had the shortest LOS for 7/10 operations and was in the lowest quartile for 2 of the other 3 operations. Variation in case-mix adjusted postoperative hospital LOS across pediatric cardiology centers has been reported previously,[13] however the implications of chest tube duration for LOS has not been previously examined. Because most centers do not discharge patients home with chest tubes,[2] the potential for an association between LOS and chest tube duration is a reasonable supposition. Earlier removal of chest tubes may affect LOS by reducing the need for sedatives and narcotics, thus potentially decreasing symptoms of nausea and promoting enteral intake. Further, for older patients, earlier removal of chest tubes may enable earlier mobilization. Postoperative LOS may be more closely linked to chest tube duration for specific surgical operation types, such as the Fontan procedure where prolonged chest tube duration and its impact on LOS have been previously documented.[14–16] However, given the many factors that impact postoperative LOS,[17] it is perhaps not surprising that consistently shorter chest tube duration for the model center did not equate to universally shorter LOS for all operation types. Nevertheless, the fact that the model center remained in the shortest tertile for all 10 procedures is intriguing.

In an effort to better understand the association between LOS and chest tube duration, PAC^3-PC^4 plans to test interventions focused on reducing chest tube duration and study the resulting impact on LOS. We utilized these baseline findings to design and implement a multicenter collaborative quality improvement project to reduce chest tube duration by decreasing variation in chest tube management practices. Similar collaborative learning approaches, including the identification of a model center's best practices, have been used by organizations such as the National Pediatric Cardiology Quality Improvement Collaborative[18] and studies such as the Pediatric Heart Networks' Collaborative Learning Study.[19] The same nine centers who participated in this baseline investigation agreed to participate in the quality improvement project beginning in June 2018. These centers have transparently shared their chest tube management processes and outcomes with one another. Drawing on these learnings, including awareness of the model center's unique practice, each center has identified its own initial approach to improve chest tube management. For example, some centers have liberalized their output volume criteria for removal of a chest tube. Cardiac Networks United [5] has provided support for data integration as well as quality improvement coaching during this intervention phase.

Limitations

It is possible that these findings may not be generalizable to other centers or operations besides the benchmark operations. Small numbers of certain operations across centers may have limited our ability to identify differences. There are likely many variables that affect chest tube drainage (e.g., use of ultrafiltration during cardiac surgery) and therefore duration, which may not all be included here. However, this may be less important given our finding that the model center successfully removes chest tubes with higher amounts of drainage. Finally, we did not compare diuretic or fluid management regimens across hospitals, however we did not see important differences in the final blood urea nitrogen or creatinine levels prior to chest tube removal.

Conclusions

In conclusion, there is significant variation in chest tube duration after congenital heart surgery across nine North American centers, with one model center demonstrating shorter chest tube duration and different management practices for the procedures studied. In addition, this model center had shorter postoperative LOS for most operations, and did not have higher rates of chest tube replacement or 7-day readmission for pleural effusion. These findings have informed an ongoing multicenter PAC^3-PC^4 collaborative quality improvement project focused on reducing post-operative chest tube duration.

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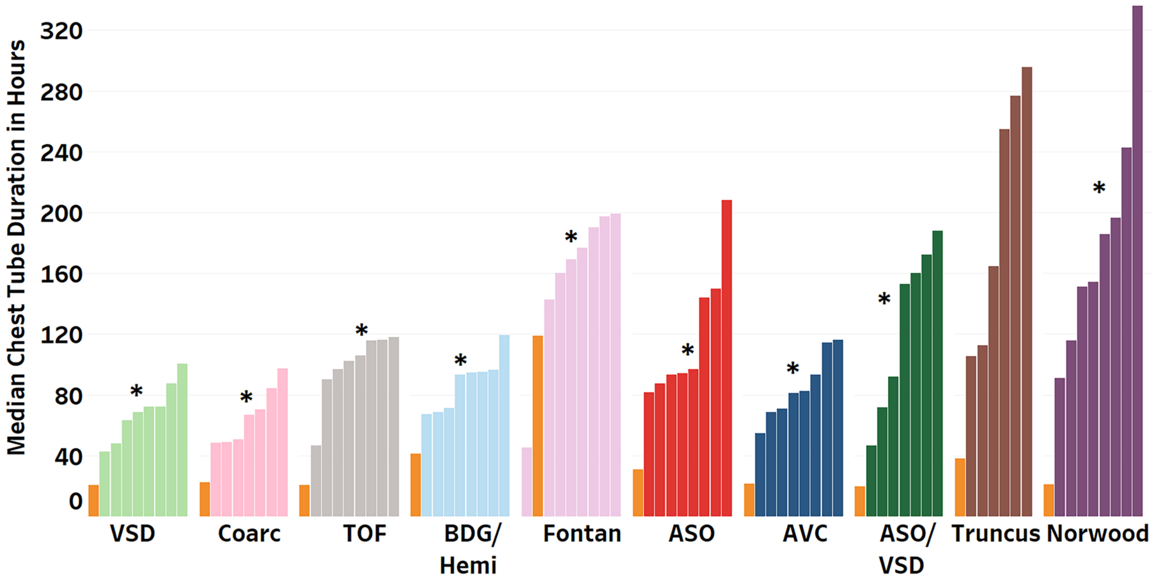

Figure 1.

Median Chest Tube Duration Across Centers by Operation Type

*indicates statistically significant difference across centers. VSD = ventricular septal defect repair, Coarc = off-bypass coarctation repair, TOF = Tetralogy of Fallot repair, BDG/Hemi = Bidirectional Glenn/HemiFontan, ASO = arterial switch operation, AVC = atrioventricular canal, truncus = truncus arteriosus repair.

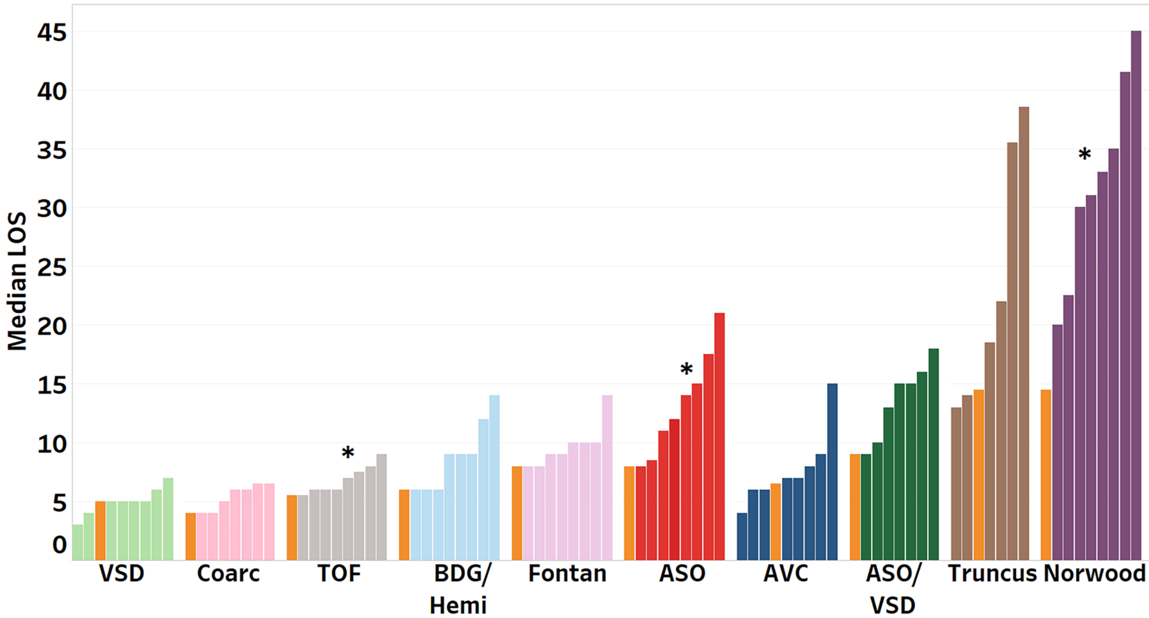

Figure 2.

Postoperative Length of Stay Across Centers by Operation type

*indicates model center length of stay is significantly shorter than other centers. VSD = ventricular septal defect repair, Coarc = off-bypass coarctation repair, TOF = Tetralogy of Fallot repair, BDG/Hemi = Bidirectional Glenn/HemiFontan, ASO = arterial switch operation, AVC = atrioventricular canal, truncus = truncus arteriosus repair.

Table 1.

Patient characteristics including comparison of model center to other sites

Characteristic	All Centers (N= 1029)	Model Center (N=228)	Other Centers (N=801)	P Value
Gestational Age[a]	38 [37, 39]	39 [37, 39]	38 [37, 39]	0.48
Age in days at Surgery	136 [34, 252]	114 [6, 205]	144 [51, 261]	**<.001**
Weight in kg at Surgery	5.57 [3.75, 7.73]	5 [3.43, 7.15]	5.67 [3.9, 8.05]	**<.001**
Number of prior cardiothoracic surgical operations[b]	0 [0, 1]	0 [0, 1]	0 [0, 1]	0.14
Extracardiac anomaly[c]	145 (14.1)	33 (14.5)	112 (14)	0.86
Genetic anomaly[c]	158 (15.4)	32 (14.0)	126 (15.8)	0.52
Presence of any syndromes or syndromic abnormalities[c]	227 (22.1)	49 (21.5)	178 (22.3)	0.80
Diagnosis of bronchopulmonary dysplasia	9 (0.9)	1 (0.4)	8 (1)	0.69
Preoperative morbidities				
Chest compressions with medications ≤48 hours prior to surgery	9 (0.9)	2 (0.9)	7 (0.9)	1.00
Mechanical circulatory support	6 (0.6)	1 (0.4)	5 (0.7)	1.00
Shock at the time of surgery	11 (1.1)	2 (0.9)	9 (1.1)	1.00
Sepsis	4 (0.4)	1 (0.4)	3 (0.4)	1.00
Renal failure	1 (0.1)	1 (0.4)	9 (1.1)	0.70
Mechanical ventilation	158 (15.4)	32 (14.0)	126 (15.8)	0.53
Respiratory syncytial virus infection	2 (0.2)	0(0)	2 (0.3)	1.00
Benchmark operation				**0.046**
Ventricular septal defect repair	190 (18.5)	33 (14.5)	157 (19.6)	
Off-bypass coarctation repair	103 (10.0)	27 (11.8)	76 (9.5)	
Tetralogy of Fallot repair	157 (15.3)	28 (12.3)	129 (16.1)	
Bidirectional Glenn/HemiFontan	146 (14.2)	30 (13.2)	116 (14.5)	
Fontan operation	127 (12.3)	25 (11)	102 (12.7)	
Arterial switch operation	74 (7.2)	26 (11.4)	48 (6.0)	
Complete atrioventricular canal repair	101 (9.8)	22 (9.7)	79 (9.9)	
Arterial switch operation and ventricular septal defect repair	25 (2.4)	5 (2.19)	20 (2.5)	
Truncus arteriosus repair	19 (1.9)	6 (2.6)	13 (1.6)	
Norwood operation	87 (8.5)	26 (11.4)	61 (7.6)	
Cardiopulmonary bypass duration in minutes[d]	98 [71, 139]	67 [51, 84]	112 [82, 153]	**<.001**
Delayed sternal closure[e]	102 (9.9)	13 (5.7)	89 (11.1)	**0.02**
Prophylactic peritoneal dialysis	10 (1.0)	0 (0.0)	10 (1.3)	0.22

All values are expressed as median [Q1, Q3], or n (%). P value is based on comparison of model center to all other sites combined.

[a] n=926 (gestational age required only if operation performed ≤365 days of life).

[b] n = 1028.

[d] n = 1027.

n = 897 (patients without any cardiopulmonary bypass not included).

[e]n= 978.

Table 2.

Model Center vs. Other Centers Median Chest Tube Duration in Hours by Operation Type

Operation	Model Center	Other Centers	P value	[a]Relative difference (%)
Ventricular septal defect repair	20.8 [17.3, 27.6]	71.1 [49, 95.6]	<0.001	70.7
Off-bypass coarctation repair	22.2 [19.1, 42.9]	67.4 [48.2, 81]	<0.001	67.1
Tetralogy of Fallot repair	20.8 [16.7, 44.4]	111 [70.9, 140]	<0.001	81.3
Bidirectional Glenn/HemiFontan	41.3 [19.6, 51.1]	89.9 [66.8, 114]	<0.001	54.0
Fontan operation	119 [92.5, 185]	165 [119, 214]	0.035	27.9
Arterial switch operation	30.8 [20, 44]	115 [81.4, 144]	<0.001	73.2
Complete atrioventricular canal repair	21.7 [19.6, 43.8]	89.5 [68.8, 120]	<0.001	75.8
Arterial switch operation and ventricular septal defect repair	19.7 [18, 22.5]	151 [107, 188]	0.002	87.0
Truncus arteriosus repair	38.2 [23.1, 71.8]	161 [113, 254]	0.002	76.3
Norwood operation	21.1[19.8, 45.4]	168 [116, 234]	<0.001	87.4

All values are expressed as median [Q1, Q3].

[a]Relative difference between the model center median chest tube duration vs. other center median chest tube duration.

For instance, in ventricular septal defect repair the median times were 20.8 hours (model) and 71.1 hours (other), resulting in a [(71.1 – 20.8)/71.1] = 70.7% shorter duration at the model center.

Table 3.

Chest tube-specific management practices and data and secondary outcomes at model center vs. other centers

Characteristic	Model Center (N=228)	Other Centers (N=801)	P Value
Management practices and data			
Number of intraoperative chest tubes placed	1 [1, 1]	2 [1, 2]	**<.001**
Need for additional postoperative chest tube placement	10 (4.7)	47 (5.9)	0.48
Chest tube output volume (mL/kg) in 24 hours prior to removal	8.5 [3.8, 16]	2.2 [1.1, 3.7]	**<.001**
Final blood urea nitrogen level (mg/dL) prior to removal[a]	14 [11, 19]	14 [10, 20]	0.73
Final creatinine (mg/dL) prior to removal[b]	0.39 [0.30, 0.50]	0.32 [0.23, 0.40]	**<.001**
Secondary Outcomes			
Chest tube replacement	3 (1.3)	17 (2.1)	0.59
Pneumothorax after chest tube removal	0 (0.0)	4 (0.5)	1.00
Readmission for pleural effusion	10 (4.4)	24 (3.0)	0.31

All values are expressed as median [Q1, Q3],

[b]trimmed mean [Q1, Q3], or n (%).

[a]n=937.