Tracheostomy is associated with decreased vasoactive-inotropic score in postoperative cardiac surgery patients on prolonged mechanical ventilation

Thomas F. O'Shea, MD,[a] Lynze R. Franko, MD,[b] Dane C. Paneitz, MD, MPH,[a,c] Kenneth T. Shelton, MD,[d] Asishana A. Osho, MD, MPH,[b,e] and Hugh G. Auchincloss, MD, MPH[b,f]

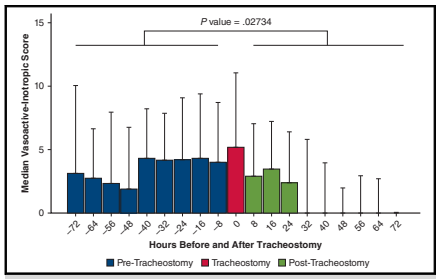
ABSTRACT

Objective: We sought to quantify the influence that tracheostomy placement has on the hemodynamic stability of postoperative cardiac surgery patients with persistent ventilatory requirements.

Methods: A retrospective, single-center, and observational analysis of postoperative cardiac surgery patients with prolonged mechanical ventilation who underwent tracheostomy placement from 2018 to 2022 was conducted. Patients were excluded if receiving mechanical circulatory support or if they had an unrelated significant complication 3 days surrounding tracheostomy placement. Vasoactive and inotropic requirements were quantified using the Vasoactive-Inotrope Score.

Results: Sixty-one patients were identified, of whom 58 met inclusion criteria. The median vasoactive-inotrope score over the 3 days before tracheostomy compared with 3 days after decreased from 3.35 days (interquartile range, 0-8.79) to 0 days (interquartile range, 0-7.79 days) ($P = .027$). Graphic representation of this trend demonstrates a clear inflection point at the time of tracheostomy. Also, after tracheostomy placement, fewer patients were on vasoactive/inotropic infusions (67.2% [n = 39] pre vs 24.1% [n = 14] post; $P < .001$) and sedative infusions (62.1% [n = 36] pre vs 27.6% [n = 16] post; $P < .001$). The percent of patients on active mechanical ventilation did not differ.

Conclusions: The median vasoactive-inotrope score in cardiac surgery patients with prolonged mechanical ventilation was significantly reduced after tracheostomy placement. There was also a significant reduction in the number of patients on vasoactive/inotropic and sedative infusions 3 days after tracheostomy. These data suggest that tracheostomy has a positive effect on the hemodynamic stability of patients after cardiac surgery and should be considered to facilitate postoperative recovery. (JTCVS Open 2024;18:138-44)



Median vasoactive-inotropic scores every 8 hours during the 72 hours before and after tracheostomy placement (hours −72 to 72).

CENTRAL MESSAGE

We provide quantitative support for the observation that tracheostomy improves hemodynamic stability in patients with ventilation requirement after cardiac surgery.

PERSPECTIVE

Tracheostomy placement in cardiac surgery patients who require prolonged ventilation is associated with reduced vasoactive and inotropic medication infusion requirements. Tracheostomy should be considered for postoperative cardiac surgery patients as a means of improving hemodynamic stability and recovery.

Acute respiratory failure is a major cause of morbidity and mortality in patients after cardiac surgery.[1-4] Prolonged mechanical ventilatory support is associated with poor clinical outcomes.[5,6] Tracheostomy in critically ill patients requiring ventilation reduces total ventilation time, intensive care unit (ICU) stay, and mortality and allows patients to remain comfortable on fewer sedating medications.[7-10] Mounting evidence supports the practice of early

From the [a]Boston University School of Medicine, Boston, Mass; [b]Department of Surgery, [d]Division of Critical Care, Department of Anesthesia, Critical Care and Pain Medicine, [c]Division of Cardiac Surgery, Corrigan Minehan Heart Center, and [f]Division of Thoracic Surgery, Massachusetts General Hospital, Boston, Mass; and [e]Department of Surgery, Johns Hopkins Hospital, Baltimore, Md.

The study protocol was approved by the Institutional Review Board (August 19, 2022; No. 2022P001926) of Massachusetts General Hospital, Boston, Mass.

Read at the 103rd Annual Meeting of The American Association for Thoracic Surgery, Los Angeles, California, May 6-9, 2023.

Received for publication May 5, 2023; revisions received Jan 24, 2024; accepted for publication Feb 2, 2024; available ahead of print March 11, 2024.

Address for reprints: Hugh G. Auchincloss, MD, MPH, Division of Thoracic Surgery, Department of Surgery, Massachusetts General Hospital, 55 Fruit St, Boston, MA 02114 (E-mail: hauchincloss@mgh.harvard.edu).

2666-2736

https://doi.org/10.1016/j.xjon.2024.02.003

Abbreviations and Acronyms
ICU = intensive care unit
STS = Society of Thoracic Surgeons
VIS = vasoactive-inotropic score

tracheostomy in cardiac surgery patients.[11-14] However, little is known about the influence of tracheostomy on the hemodynamic stability of patients undergoing cardiac surgery.

High doses of inotropic and vasoactive medications are associated with poor outcomes in cardiac surgery patients.[15] Recent studies in both pediatric and adult cardiac surgery patients have established the use of the vasoactive-inotrope score (VIS) to quantify the amount of vasoactive and inotropic support required, and standardized it for use as a predictive measure.[16-18] VIS is a weighted sum of all administered inotropes and vasopressors and has been validated as a tool in cardiac surgery populations.[16,19-21]

We have observed that patients undergoing cardiac surgery with prolonged ventilation requirements have improved hemodynamic stability after tracheostomy placement. We primarily sought to investigate if tracheostomy placement does have an influence on VIS score and hemodynamic stability. We also desired to quantify this effect, if present, by measuring VIS pre- and posttracheostomy in a cohort of patients undergoing cardiac surgery, and hypothesized that a visual representation of the decreasing VIS in this population would demonstrate an inflection point at the time of tracheostomy.

METHODS

Study Design

The study protocol was approved by the Institutional Review Board (August 19, 2022; No. 2022P001926) of Massachusetts General Hospital. We conducted a retrospective observational cohort study of adult cardiac surgery patients (aged 18 years or older) who were within our institutional Society of Thoracic Surgeons (STS) database, required prolonged mechanical ventilation as defined by the STS (>24 hours), and underwent tracheostomy placement from September 1, 2018, to May 31, 2022, for respiratory failure at Massachusetts General Hospital. Patients were excluded if they were on mechanical circulatory support or had an unrelated significant complication (such as abdominal compartment syndrome) 3 days before or after tracheostomy placement. The STS database was used to capture patient age, gender, past medical history, procedure type, cardiopulmonary bypass time, aortic crossclamp time, operative mortality, postoperative complications, total mechanical ventilation time, and readmission rates. Chart review was conducted for each patient to collect vasoactive, antiarrhythmic, and sedative infusion drugs and rates, mechanical ventilation requirements, and hemodynamic data. Arterial line was used as the primary method of hemodynamic monitoring. Noninvasive blood pressure cuff was utilized if arterial line was not in place. Data were recorded at a point in time every 8 hours for 3 days before and after tracheostomy placement. Details of the tracheostomy procedure were taken from the patient chart and STS database, including procedure location, days from index cardiac surgery, anticoagulation dosing on the day of the procedure, complications, and tracheostomy decannulation status at discharge. Three tracheostomies were performed in the operating room using an open technique, and all others were performed in percutaneous fashion using accepted technique as previously described by our group.[21]

Statistical Analysis

Descriptive statistics were used to summarize the demographics and clinical characteristics of the entire cohort with continuous variables being reported as median value (IQR) and categorical variables reported as whole number (%). Characteristics of the tracheostomy procedures were summarized in a similar fashion. The number of patients who required specific vasoactive or inotropic drugs were reported as whole number (%). To assess our primary outcome of the effect that tracheostomy has on vasoactive supportive requirement; VIS was calculated at every 8 hours 3 days before and after tracheostomy placement using the formula:[21,22]

$$\begin{aligned}\text{VIS} = {} & \text{dopamine dose}\left[\mu g\ kg^{-1}\ min^{-1}\right] + \text{dobutamine}\left[\mu g\ kg^{-1}\ min^{-1}\right] + 100\times\text{epinephrine dose} \\ & \left[\mu g\ kg^{-1}\ min^{-1}\right] + 50\ \text{levosimendan dose}\left[\mu g\ kg^{-1}\ min^{-1}\right] + 10\times\text{milrinone dose}\left[\mu g\ kg^{-1}\ min^{-1}\right] \\ & + 10\,000\times\text{vasopressin dose}\left[\text{units}\ kg^{-1}\ min^{-1}\right] + 100\times\text{norepinephrine dose}\left[\mu g\ kg^{-1}\ min^{-1}\right] \\ & + 10\times\text{phenylephrine dose}\left[\mu g\ kg^{-1}\ min^{-1}\right]\end{aligned}$$

Median VIS and mean arterial pressure were compared for the 3 days before and 3 days after tracheostomy utilizing a Wilcoxon signed-rank test. The presence of vasoactive/inotropic, antiarrhythmic, and sedative infusions as well as mechanical ventilation at 3 days pre-vs posttracheostomy were represented as whole number (%) and compared utilizing McNemar test. A 2-tailed P value < .05 was used to determine statistical significance. Data were collected using REDCap software (Vanderbilt University), and statistical analysis was performed using Stata 17 (StataCorp LLC) and R Studio (R Foundation for Statistical Computing).

RESULTS

Patient Demographics and Clinical Characteristics

There were 4474 cardiac surgery patients during the time frame that met criteria for the STS database. Sixty-one patients identified met inclusion criteria, 3 were excluded due to either requiring mechanical circulatory support (n = 1) or experiencing an unrelated significant complication (n = 2) within the 3-day window before or after tracheostomy placement. The majority of patients were men with a median age of 68 years (IQR, 63-75.5 years) and body mass index of 28.0 (IQR, 25.0-30.9) (Table 1). The majority of patients were current or former smokers; 36.2% had a history of chronic lung disease; and 1 patient required home oxygen.

TABLE 1. Patient demographics and clinical characteristics

Characteristic	Patients (N = 58)
Demographics and characteristics	
Age (y)	68 (63-75.5)
Men	36 (62.1)
Diabetes	24 (41.3)
BMI	28 (25.0-30.9)
Peripheral vascular disease	15 (25.8)
Cerebrovascular disease	23 (39.6)
History of heart failure	41 (70.7)
Smoking history	
Never	19 (32.8)
Former	26 (44.8)
Current	13 (22.4)
Chronic lung disease (%)	21 (36.2)
Home oxygen	1 (1.7)
Urgent/emergency procedure	39 (67.2)
Procedure	
Isolated CABG	6 (10.3)
Isolated AVR	2 (3.4)
MVR/CABG	4 (6.8)
AVR/MVR	5 (8.6)
Mitral valve repair	4 (6.8)
Other	37 (61.4)
Cardiopulmonary bypass time (min)	216 (155.5-297.7)
Crossclamp time (min)	145 (105.3-223.3)
Day of tracheostomy placement (postoperative day)	12 (10-14)
ICU duration (h)	578 (410-778)
Index patient outcomes	
Operative mortality	13 (22.4)
Mechanical ventilation (h)	482 (322.1.5-685)
ICU (h)	578 (410-778)
Pneumonia	33 (56.9)
Sepsis	14 (24.1)
Deep vein thrombosis	11 (19.0)
Pulmonary embolism	2 (3.4)
Renal failure	31 (53.4)
Atrial fibrillation	33 (56.8)
Stroke	6 (10.3)
Reoperation for bleeding	12 (20.7)
Readmission	16 (27.6)

Values are presented as median (interquartile range) or n (%). *BMI*, Body mass index; *CABG*, coronary artery bypass grafting; *AVR*, aortic valve replacement; *MVR*, mitral valve replacement; *ICU*, intensive care unit.

The median cardiopulmonary bypass time was 216 minutes (IQR, 155.5-297.7 minutes), and aortic cross clamp time was 145 minutes (105.3-223.3 minutes) (Table 1). Postoperatively, all patients required prolonged mechanical ventilation of 24 hours or greater with a median ventilation time of 482 hours (IQR, 322.1-685) (Table 1). The median postoperative day of tracheostomy placement was 12 days (IQR, 10-14 days) (Table 1). The median number of hours spent in the ICU was 578 hours (IQR, 410-778 hours) (Table 1). The all-cause mortality from time of index operation until 30 days after surgery for the cohort was 22.4% (n = 13) (Table 1).

TABLE 2. Characteristics of tracheostomy placement procedures

Characteristic	Result
Days from index cardiac surgery	13 (11-16)
Procedure location	
Bedside	55 (94.8)
Operating room	3 (5.2)
Anticoagulation on day of tracheostomy placement	
Therapeutic	24 (44.8)
Prophylactic or subtherapeutic	26 (48.3)
None	4 (6.9)
Complications	
Bleeding requiring stopping anticoagulation	1 (1.7)
Bleeding requiring stopping anticoagulation and bronchoscopy	1 (1.7)
Other complications*	0 (0)
No complications	56 (96.6)
Requiring exchange of tracheostomy during the first 5 d	2 (3.4)
Tracheostomy decannulated before discharge	
Yes	30 (51.7)

Values are presented as median (interquartile range) or n (%). *Other complications include pneumomediastinum, pneumothorax, failure of tracheostomy placement, subcutaneous emphysema, esophageal injury, and recurrent laryngeal injury.

Tracheostomy Characteristics

The majority of tracheostomy procedures (94.8%) occurred at the bedside and were performed percutaneously (Table 2). Therapeutic anticoagulation on the day of their procedure was present in 44.8% of patients (Table 2). The majority of patients (96.6%) experienced no postprocedure complications (Table 2). The most common postprocedure complication was bleeding, which 2 patients experienced and required halting of their anticoagulation. Also, 1 of these patients required bronchoscopy. Only 2 patients required exchange of their tracheostomy within the first 5 days, and 30 (51.7%) of patients were decannulated before discharge (Table 2).

Tracheostomy Placement Association With Vasoactive and Inotropic Requirements

Norepinephrine was the most frequently used vasoactive or inotropic medication with 91.4% of patients (n = 53) requiring it, followed by vasopressin at 41.4% (n = 24) and epinephrine at 24.1% (n = 14) (Table 3). The median VIS decreased from 3.35 (IQR, 0-8.79) to 0 (IQR, 0-7.79) in the 3-day period before compared with the 3-day period after tracheostomy placement ($P = .027$) (Table 4 and Figure 1). There were also fewer patients requiring vasoactive (67.2% [n = 39] before vs 24.1% [n = 14] after [$P < .001$]) and sedative (62.1% [n = 36] before vs 27.6% [n = 16] after [$P < .001$]) continuous infusions at 72 hours after tracheostomy placement compared with 72 hours before (Table 5). There was no difference in mechanical ventilation, antiarrhythmic requirements, or

TABLE 3. Patients requiring specific vasoactive drugs during the 72 hours before and after tracheostomy placement

Vasoactive medication	Result N (%)
Dopamine	2 (3.4)
Dobutamine	2 (3.4)
Epinephrine	14 (24.1)
Milrinone	8 (13.8)
Norepinephrine	53 (91.4)
Phenylephrine	5 (8.6)
Vasopressin	24 (41.4)

Values are presented as n (%).

TABLE 4. Comparison of vasoactive-inotropic score and mean arterial pressure pre- and posttracheostomy

Measurement	Pretracheostomy	Posttracheostomy	*P* value*
Vasoactive-inotropic score	3.35 (0-8.79)	0 (0-7.79)	.027
Mean arterial pressure	73 (68-78)	74 (68-81)	.202

Values are presented as median (interquartile range). *Wilcoxon signed-rank test.

mean arterial pressure in the 3 days before and after tracheostomy placement (Table 4).

DISCUSSION

Most cardiac surgery patients do not require ventilatory support beyond a few hours from the end of the procedure. However, those who do have higher rates of morbidity and mortality.[1-3,23,24] Understanding which interventions best serve to rescue these patients is paramount. Our study adds to the growing body of literature supporting the use tracheostomy to aid in postoperative recovery of cardiac surgery patients who require prolonged ventilation. We demonstrate that tracheostomy placement in this cohort is followed by a significant decrease in overall VIS and in the number of patients requiring any vasoactive or inotropic support. This analysis is consistent with the hypothesis that tracheostomy placement has a positive influence on the hemodynamic stability of postoperative cardiac surgery patients.

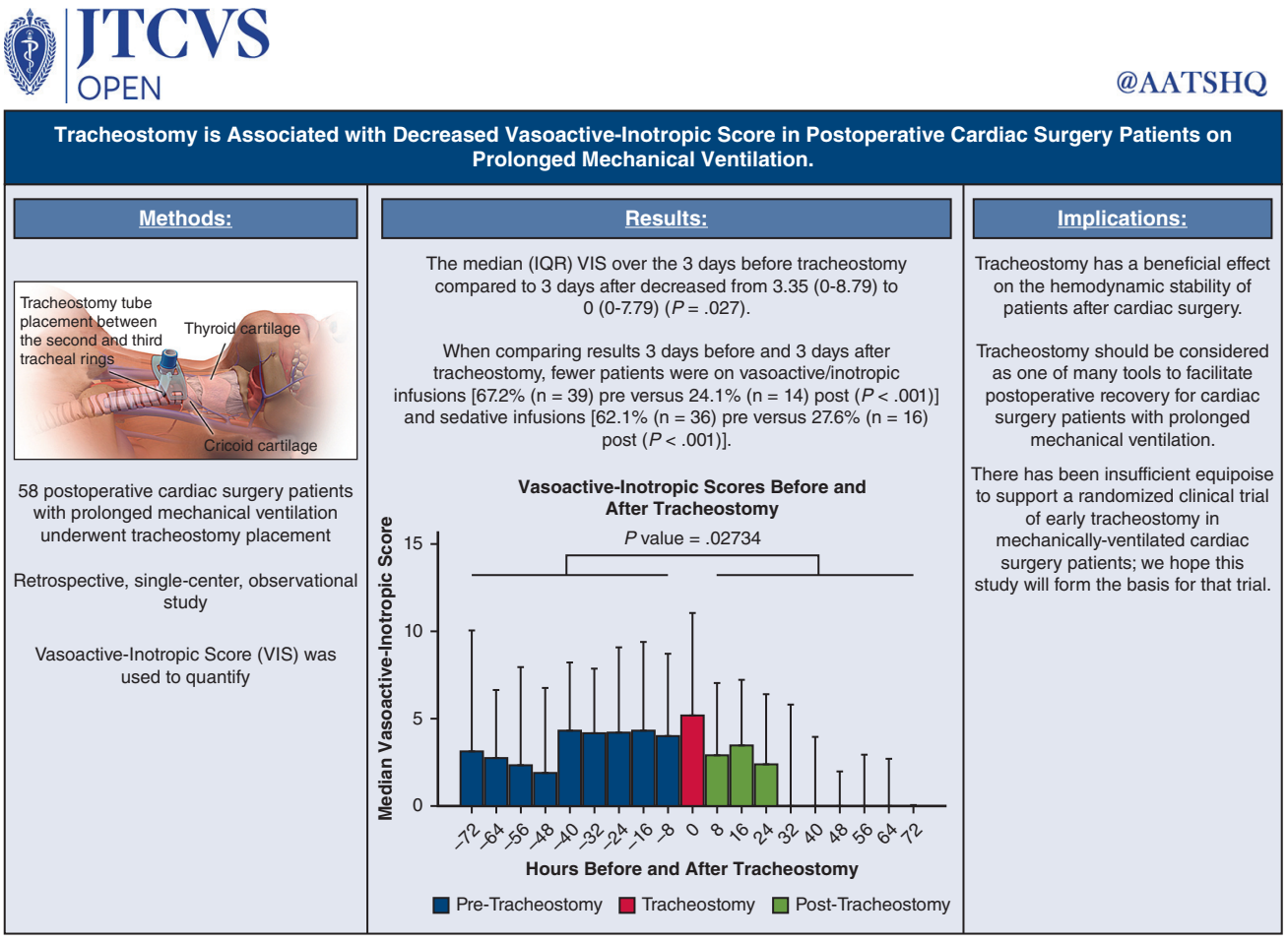


FIGURE 1. Graphical abstract.

TABLE 5. Patients requiring vasoactive and sedative continuous infusions, mechanical ventilation, and antiarrhythmic requirements during the 72 hours before and after tracheostomy

Variable	72 h before tracheostomy	At 72 h after tracheostomy	*P* value*
Continuous sedative medication	36 (62.1)	16 (27.6)	<.001
Continuous vasoactive medication	39 (67.2)	14 (24.1)	<.001
Mechanically ventilation	47 (75.9)	49 (84.5)	.814
Continuous antiarrhythmic	12 (20.7)	9 (15.5)	.773

Values are presented as n (%). *McNemar test.

A previous study by Nieszkowska and colleagues[10] examined the effect of tracheostomy on sedative requirements and found there were fewer patients requiring continuous sedative medication after tracheostomy placement. Our study uses similar methods to show the association between tracheostomy placement and decreased vasoactive and inotropic requirements. Our analysis also found that tracheostomy placement was associated with decreased sedative requirements. There was a peak in VIS on the day of tracheostomy placement, which was likely due to sedation and paralysis given with tracheostomy placement. Unlike other studies, our cohort did not demonstrate a decrease in short-term mechanical ventilation requirement after tracheostomy placement.[10,13,25] This factor could be due to limiting data collection to only 72 hours after tracheostomy. Additionally, it is likely this patient population with significant complications, respiratory failure, and other comorbidities required more than 72 hours to gain the strength and clinical stability needed to breathe spontaneously off of mechanical ventilation.

All of the patients in our cohort had a tracheostomy placed in percutaneous fashion in the ICU except for 3 patients who had open tracheostomies placed. Complications were infrequent and minimal. Only 2 patients experienced a bleeding complication requiring intervention, despite almost all patients being either therapeutically or prophylactically anticoagulated on the day of the procedure. There were no surgical site infections, esophageal injuries, recurrent laryngeal nerve injuries, pneumothoraces, or pneumomediastinums. Two patients required tracheostomy exchange within 5 days of placement. Most patients were decannulated before discharge.

The strength of our study is in the granularity of our data. We were able to perform a careful chart review of every patient and gather precise information about hemodynamic support and its relationship to tracheostomy placement. Our study has limitations related to small sample size, retrospective and observational nature, and lack of a control group. We did not believe that it was possible to construct a control group from the population of patients who had prolonged ventilatory requirements but did not receive a tracheostomy because there were certain to be unmeasured confounders for which no propensity score or other regression model could properly account. Previously, there was

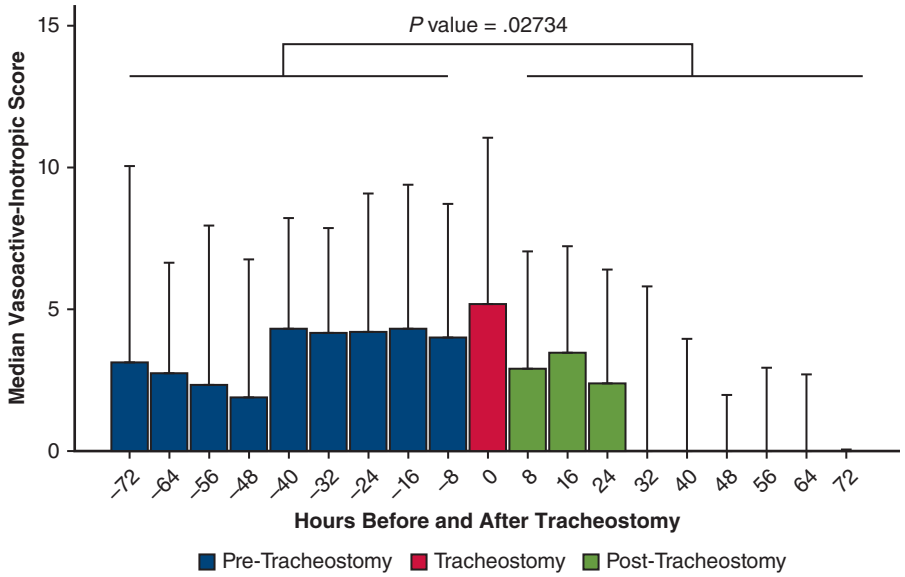


FIGURE 2. Median vasoactive-inotropic scores every 8 hours during the 72 hours before and after tracheostomy placement (hours −72 to 72). Data are expressed as median values and 75th percentiles (upper error bar of bar graph). Wilcoxon signed-rank test was used to compare the median vasoactive-inotropic score pre- and posttracheostomy placement.

insufficient equipoise to support a randomized clinical trial of early tracheostomy in patients undergoing cardiac surgery who are mechanically ventilated. We hope this study will form the basis for that trial. This study did have a median age of 68 years, which is younger than potentially would be expected. This could be because older patients and their families in this cohort with prolonged respiratory failure and additional complications chose not to undergo tracheostomy; however, these data were not examined in this study.

We are unable to draw from our study any conclusions about the mechanism by which tracheostomy improves hemodynamic stability in patients undergoing cardiac surgery, nor to even prove that such a causal relationship exists. Despite establishing temporal precedence and covariance, we are unable to disqualify alternative explanations of this phenomenon. It is possible that we are simply observing the general trend in hemodynamic improvement that comes with time and is incidental to tracheostomy placement, or that tracheostomy placement is not requested until a trend of hemodynamic stability is observed. However, our graphic representation showing a clear inflection point in hemodynamic stability immediately following tracheostomy placement is consistent with the latter event precipitating the former. With regard to mechanism, we suspect that a combination of decreased sedation burden and improved ventilatory compliance associated with tracheostomy placement accounts for the observed effect. Further studies involving invasive and noninvasive hemodynamic testing at the time of tracheostomy will be helpful in providing clarity.

CONCLUSIONS

This study demonstrates that tracheostomy placement is associated with improved hemodynamic stability in postoperative cardiac surgery patients who require prolonged mechanical ventilation (Figure 2). This population is at high risk for morbidity and mortality, and tracheostomy should be considered as among many tools to facilitate postoperative recovery and improve overall outcome. However, multicenter studies are needed to fully establish a causal relationship between tracheostomy and improved hemodynamic stability in patients undergoing cardiac surgery.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

References

1. Rong LQ, di Franco A, Gaudino M. Acute respiratory distress syndrome after cardiac surgery. *J Thorac Dis*. 2016;8(10):E1177-E1186. https://doi.org/10.21037/JTD.2016.10.74
2. Murthy SC, Arroliga AC, Walts PA, et al. Ventilatory dependency after cardiovascular surgery. *J Thorac Cardiovasc Surg*. 2007;134(2):484-490.e6. https://doi.org/10.1016/J.JTCVS.2007.03.006
3. Stephens RS, Shah AS, Whitman GJR. Lung injury and acute respiratory distress syndrome after cardiac surgery. *Ann Thorac Surg*. 2013;95(3):1122-1129. https://doi.org/10.1016/J.ATHORACSUR.2012.10.024
4. Milot J, Perron J, Lacasse Y, Létourneau L, Cartier PC, Maltais F. Incidence and predictors of ARDS after cardiac surgery. *Chest*. 2001;119(3):884-888. https://doi.org/10.1378/CHEST.119.3.884
5. Fernandez-Zamora MD, Gordillo-Brenes A, Banderas-Bravo E, et al. Prolonged mechanical ventilation as a predictor of mortality after cardiac surgery. *Respir Care*. 2018;63(5):550-557. https://doi.org/10.4187/RESPCARE.04915
6. Suarez-Pierre A, Fraser CD, Zhou X, et al. Predictors of operative mortality among cardiac surgery patients with prolonged ventilation. *J Card Surg*. 2019;34(9):759-766. https://doi.org/10.1111/JOCS.14118
7. Arabi Y, Haddad S, Shirawi N, al Shimemeri A. Early tracheostomy in intensive care trauma patients improves resource utilization: a cohort study and literature review. *Crit Care*. 2004;8(5):1-6. https://doi.org/10.1186/CC2924
8. Rumbak MJ, Newton M, Truncale T, Schwartz SW, Adams JW, Hazard PB. A prospective, randomized, study comparing early percutaneous dilational tracheotomy to prolonged translaryngeal intubation (delayed tracheotomy) in critically ill medical patients. *Crit Care Med*. 2004;32(8):1689-1694. https://doi.org/10.1097/01.CCM.0000134835.05161.B6
9. Davis K, Campbell RS, Johannigman JA, Valente JF, Branson RD. Changes in respiratory mechanics after tracheostomy. *Arch Surg*. 1999;134(1):59-62. https://doi.org/10.1001/ARCHSURG.134.1.59
10. Nieszkowska A, Combes A, Luyt CE, et al. Impact of tracheotomy on sedative administration, sedation level, and comfort of mechanically ventilated intensive care unit patients. *Crit Care Med*. 2005;33(11):2527-2533. https://doi.org/10.1097/01.CCM.0000186898.58709.aa
11. Devarajan J, Vydyanathan A, Xu M, et al. Early tracheostomy is associated with improved outcomes in patients who require prolonged mechanical ventilation after cardiac surgery. *J Am Coll Surg*. 2012;214(6):1008-1016.e4. https://doi.org/10.1016/J.JAMCOLLSURG.2012.03.005
12. Affronti A, Casali F, Eusebi P, et al. Early versus late tracheostomy in cardiac surgical patients: a 12-year single center experience. *J Cardiothorac Vasc Anesth*. 2019;33(1):82-90. https://doi.org/10.1053/J.JVCA.2018.05.041
13. Trouillet JL, Luyt CE, Guiguet M, et al. Early percutaneous tracheotomy versus prolonged intubation of mechanically ventilated patients after cardiac surgery: a randomized trial. *Ann Intern Med*. 2011;154(6):373-383. https://doi.org/10.7326/0003-4819-154-6-201103150-00002
14. Sareh S, Toppen W, Ugarte R, et al. Impact of early tracheostomy on outcomes after cardiac surgery: a national analysis. *Ann Thorac Surg*. 2021;111(5):1537-1544. https://doi.org/10.1016/J.ATHORACSUR.2020.07.027
15. Shahin J, deVarennes B, Tse CW, Amarica DA, Dial S. The relationship between inotrope exposure, six-hour postoperative physiological variables, hospital mortality and renal dysfunction in patients undergoing cardiac surgery. *Crit Care*. 2011;15(4):R162. https://doi.org/10.1186/CC10302
16. Gaies MG, Gurney JG, Yen AH, et al. Vasoactive-inotropic score as a predictor of morbidity and mortality in infants after cardiopulmonary bypass. *Pediatr Crit Care Med*. 2010;11(2):234-238. https://doi.org/10.1097/PCC.0B013E3181B806FC
17. Yamazaki Y, Oba K, Matsui Y, Morimoto Y. Vasoactive-inotropic score as a predictor of morbidity and mortality in adults after cardiac surgery with cardiopulmonary bypass. *J Anesth*. 2018;32(2):167-173. https://doi.org/10.1007/S00540-018-2447-2
18. Koponen T, Karttunen J, Musialowicz T, Pietiläinen L, Uusaro A, Lahtinen P. Vasoactive-inotropic score and the prediction of morbidity and mortality after cardiac surgery. *Br J Anaesth*. 2019;122(4):428-436. https://doi.org/10.1016/J.BJA.2018.12.019
19. Boss K, Jahn M, Wendt D, et al. Extracorporeal cytokine adsorption: significant reduction of catecholamine requirement in patients with AKI and septic shock after cardiac surgery. *PLoS One*. 2021;16(2):e0246299. https://doi.org/10.1371/JOURNAL.PONE.0246299
20. Silahli M, Tekin M, Çelik M. Vasoactive inotropic score for predicting pediatric tracheostomy. *Iran Red Cresc Med J*. 2022;24(10):e1088. https://doi.org/10.32592/ircmj.2022.24.10.1088
21. Belletti A, Lerose CC, Zangrillo A, Landoni G. Vasoactive-inotropic score: evolution, clinical utility, and pitfalls. *J Cardiothorac Vasc Anesth*. 2021;35(10):3067-3077.
22. Hashimoto DA, Axtell AL, Auchincloss HG. Percutaneous tracheostomy. *N Engl J Med*. 2020;383(20):e112. https://doi.org/10.1056/NEJMvcm2014884

23. McIsaac DI, Bernard McDonald F, Coralie Wong FA, et al. Long-term survival and resource use in critically ill cardiac surgery patients: a population-based study. *Can J Anesth*. 2018;65(9):985-995. https://doi.org/10.1007/s12630-018-1159-2
24. Hein OV, Birnbaum J, Wernecke KD, Konertz W, Jain U, Spies C. Three-year survival after four major post-cardiac operative complications. *Crit Care Med*. 2006;34(11):2729-2737. https://doi.org/10.1097/01.CCM.0000242519.71319.AD
25. Boynton JH, Hawkins K, Eastridge BJ, O'Keefe GE. Tracheostomy timing and the duration of weaning in patients with acute respiratory failure. *Crit Care*. 2004;8(4):1-7. https://doi.org/10.1186/CC2885/FIGURES/2

Key Words: tracheostomy, cardiac surgery, hemodynamic stability, perioperative management