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Prolonged postoperative respiratory support after proximal thoracic aortic surgery: Is deep hypothermic circulatory arrest a risk factor?☆,☆☆,★

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Abstract

Purpose—In addition to the pulmonary risks associated with cardiopulmonary bypass, thoracic aortic surgery using deep hypothermic circulatory arrest (DHCA) may subject the lungs to further injury. However, this topic has received little investigation to date.

Materials and Methods—A prospective cohort review was performed on all patients undergoing proximal thoracic aortic surgery with (n = 478) and without (n = 135) DHCA between July 2005 and February 2013 at a single institution. The primary outcome was prolonged postoperative respiratory support (PPRS), defined as any of the following: >1 day of mechanical ventilation at either fraction of inspired oxygen >0.4 and/or positive end-expiratory pressure >5 mm Hg, >2 days of supplemental O_2 requirement of at least 2.5 L/min, or discharge with new O_2 requirement. Independent risk factors for PPRS were identified using multivariable logistic regression.

Results—Postoperative respiratory support was required in 100 patients (20.9%) with and 30 patients (22.2%) without DHCA ($P = .74$). Independent predictors of PPRS after proximal aortic surgery included the following: age, diabetes, history of stroke, preoperative creatinine, American Society of Anesthesiologists class 4, redo-sternotomy, total arch replacement, and transfusion requirement. Use of DHCA was not an independent risk factor for PPRS in the entire cohort.

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Subanalysis of only DHCA patients revealed that longer DHCA times were independently associated with PPRS.

Conclusions—Prolonged postoperative respiratory support is common after proximal aortic surgery. The use of DHCA was not associated with this complication in the overall cohort, although longer DHCA times were predictive when only the subset of patients undergoing DHCA was analyzed. Knowledge of the risk factors for PPRS after proximal aortic surgery should improve preoperative risk stratification and postoperative management of these patients.

Keywords

Aorta; Circulatory arrest; Deep hypothermia induced; Respiration; Risk factors; Thoracic surgical procedures

1. Introduction

Respiratory dysfunction is common after cardiac surgery involving cardiopulmonary bypass (CPB) and can range from asymptomatic spirometric changes to fulminant acute respiratory distress syndrome [1–4]. Postoperative respiratory complications such as hypoxemia, prolonged ventilation, and respiratory failure contribute to increased patient morbidity, mortality, and health care expenditures, and are believed to be initiated by the systemic inflammatory response elicited by the CPB circuit [4].

In proximal thoracic aortic surgery, deep hypothermic circulatory arrest (DHCA) in addition to CPB facilitates reconstruction of the arch and great vessels by allowing a bloodless field during surgical repair. However, the use of DHCA subjects the lungs to additional injury beyond the adverse pulmonary effects of CPB, including ischemia-reperfusion injury [5]. Moreover, thoracic aortic surgery often involves significant transfusion, which may further exacerbate perioperative lung injury [2]. Although these insults may result in prolonged ventilator or oxygen requirements, detailed descriptions of risk factors for prolonged postoperative respiratory support (PPRS) in this population are lacking.

Understanding risk factors for PPRS in patients undergoing thoracic aortic surgery with DHCA may allow for optimization of perioperative clinical management strategies and improve preoperative risk stratification. As such, the current study sought to determine risk factors for PPRS based on patient-level variables, including the use of DHCA, and secondarily examine whether PPRS is associated with other adverse clinical outcomes.

2. Materials and methods

All patients undergoing open proximal (root or supracoronary ascending [±aortic valve] and ±aortic arch) thoracic aortic surgery via median sternotomy between July 2005 and February 2013 at a single tertiary referral institution (Duke University Medical Center, Durham, NC) were included in the study. Data were obtained from the Duke Thoracic Aortic Surgery Database, a prospectively maintained clinical registry of all patients undergoing thoracic aortic surgery at Duke since June 2005. The study was approved by the Duke Institutional Review Board, and the need for individual patient consent was waived.

Conduct of surgical procedures was as previously described [6–8]. Ventilator management, extubation, and postextubation care including supplemental oxygen delivery are strictly protocolized as described in e-Appendix 1.

Prolonged postoperative respiratory support was defined as any of the following: >1 day of mechanical ventilation at either fraction of inspired oxygen >0.4 and/or positive end-expiratory pressure >5 mm Hg, >2 days of supplemental O_2 requirement of at least 2.5 L/min, or discharge with a new O_2 requirement. This definition of PPRS was chosen so as to separate patients requiring respiratory support due to pulmonary issues from patients on ventilator support for other reasons (ie, altered mental status, open chest, and hemorrhagic complications). Because there is no protocol for starting or stopping supplemental oxygen, the flow rate limits were also chosen in an attempt to identify those patients truly in need of respiratory support. A day was defined as at least 8 consecutive hours during a 24-hour period, again to help identify those patients with true pulmonary issues requiring support.

Candidate variables for risk factor analysis were based on analysis of the existing literature (Table 1) [9–13]. Number of blood products transfused perioperatively was defined as total units of red blood cells, fresh-frozen plasma, cryoprecipitate, and apheresis platelet units administered within 72 hours from the start of surgery.

In order to determine which clinical and patient characteristics are associated with PPRS in patients undergoing proximal thoracic aortic surgery, a multivariable logistic regression model using the candidate risk variables was generated. A forward selection procedure was used, in which the variable with the lowest *P* value was included in the model first. Subsequent predictors were added to the model and retained only if they added significant predictive ability to the variables already included. Variables that became nonsignificant in the presence of new significant predictors were dropped from the model. In order to determine whether DHCA is a risk factor for the development of PPRS, the incidence of PPRS in patients undergoing open proximal aortic surgery with and without DHCA was compared, and the use of DHCA was included as a variable within the model. Intraoperative variables, including the use of DHCA, were tested individually and then added to the preoperative model so as to reduce confounding.

To further investigate the potential role longer DHCA periods might have on the development of PPRS, subgroup analysis was performed only for patients undergoing proximal aortic surgery using DHCA. A separate multivariate logistic model was generated using the same variables and methodology described above. Because all patients within this subanalysis had DHCA, the duration of DHCA was included as a continuous variable in the model.

To determine the effect of PPRS on early outcomes after proximal thoracic aortic surgery, multivariate regression models were constructed for both prolonged length of stay (defined as >7 days) and discharge disposition to other than home (ie, long-term acute care, skilled nursing, or rehabilitation facility) using a forward selection procedure. All preoperative and intraoperative variables described above were included, with PPRS added to the final model as a dichotomous variable. To test whether PPRS is associated with decreased late survival after proximal thoracic aortic surgery, we constructed Kaplan-Meier curves comparing the survival of patients with PPRS to those without this complication. Survival data were obtained from the medical record, the Social Security Death Index, and the DEDUCE-guided query tool [14]. Statistical analysis was performed using SAS version 9.2 (Cary, NC).

3. Results

Six hundred thirteen patients underwent elective or nonelective open proximal thoracic aortic surgery between July 2005 and February 2013; n = 478 (78.0%) procedures were performed with and n = 135 (22.0%) without DHCA. Patient demographics are listed in Table 1. Overall 30-day and 1-year mortality was 3.4% (n = 21) and 7.5% (n = 46), respectively. Procedures included supracoronary ascending aorta ± hemi-arch replacement (n = 168), ascending aorta + aortic valve replacement (Wheat procedure) ± hemi-arch replacement (n = 129), valved conduit aortic root replacement (Bentall procedure) ± hemi-arch replacement (n = 202), valve-sparing aortic root replacement (David procedure) ± hemi-arch replacement (n = 47), total arch replacement (n = 42), sinus of Valsalva aneurysm repair (n = 5), and other (n = 20). Concomitant procedures were performed in 194 (31.6%) patients, of which 105 were coronary artery bypass grafting (CABG).

One hundred thirty (21.2%) patients required PPRS (Table 2). The rate of PPRS was similar between patients who underwent proximal aortic surgery with (100/478; 20.9%) or without (30/135; 22.2%) DHCA ($P = .74$). Univariate predictors of PPRS after proximal thoracic aortic surgery are presented in Table 3. Following multivariable analysis, a total of 8 independent predictors of PPRS remained (Table 4): patient age, diabetes, history of stroke, preoperative creatinine, American Society of Anesthesiologists (ASA) class 4, redo-sternotomy, total arch replacement, and transfusion requirement within the first 72 hours. This model explained the majority of risk for PPRS, with a *C* index of 0.74.

Although the use of DHCA was not an independent risk factor for PPRS in the multivariable model, most patients undergoing DHCA as part of their proximal aortic repair had relatively short DHCA periods. Therefore, to investigate whether the duration of DHCA might be associated with requirement for PPRS, a subanalysis was performed examining only those patients undergoing DHCA as part of their procedure (n = 478) and adding DHCA time as a continuous variable to the previously developed model for PPRS. By this subanalysis, longer DHCA time was independently associated with PPRS (per 15 minutes; odds ratio [OR], 2.18; 95% confidence interval [CI], 1.33–3.23; $P = .001$), although this addition only slightly improved the previous model (*C* index = 0.75).

Median postoperative length of stay for the entire cohort was 6 days (interquartile range [IQR]: 5–9 days), and 62 patients (10.1%) were discharged to somewhere other than home. Patients with PPRS had significantly longer length of stay compared with those who did not, and also were more likely to be discharged to somewhere other than home ($P < .0001$ for both; Table 5). In multivariate analysis, PPRS was independently associated with prolonged hospital length of stay (OR, 9.78; 95% CI, 5.76–16.6; $P < .0001$) and discharge to other than home (OR, 3.36; 95% CI, 1.81–6.25; $P < .0001$).

Overall in-hospital mortality was 3.9% (n = 24) and was significantly higher in patients who developed PPRS (8.5% vs 2.7%, $P = .003$; Table 5). For the survival analysis, all patients were followed up for at least 1 year (median follow-up, 1426 days; IQR, 823–2084 days), and 79 patients died during follow-up. Kaplan-Meier survival analysis showed a significant decrease in late survival among patients who required PPRS vs non-PPRS patients (log-rank test, $P < .0001$; Fig. 1). Analysis of the survival curves suggests that this survival difference is primarily due to the significantly lower 1-year survival (81.5%) for PPRS patients vs non-PPRS patients (95.5%), likely reflecting lingering effects of perioperative events, and that PPRS and non-PPRS patients who survive 1 year have similar long-term survival thereafter based on the parallel slope of the curves.

4. Discussion

Pulmonary dysfunction after thoracic aortic surgery is a not uncommon event. Previous studies have described rates of postoperative respiratory dysfunction ranging from 9% to 19% [9–12]. Although the event rate was higher (21.2%) in the current study, this difference likely has to do with the definition of prolonged respiratory support used. In the previous literature, pulmonary complications were defined as either greater than 72 hours [9,10,12] or 5 days [11] of mechanical ventilation, and only one study [9] excluded patients requiring prolonged ventilation due to nonpulmonary issues (ie, neurological injury or low cardiac output). No prior study on this topic has included prolonged use of supplemental oxygen as part of the criteria for respiratory support. However, an inability to wean supplemental oxygen suggests underlying pulmonary compromise and was therefore included in the current analysis.

The current study identified age, diabetes, history of stroke, preoperative creatinine, ASA class 4, redo-sternotomy, total arch replacement, and volume of blood product transfusion as independent risk factors for PPRS after proximal thoracic aortic surgery. Although the use of DHCA was not associated with PPRS within the entire cohort, when only considering patients where DHCA was used, longer arrest times were associated with the need for PPRS. This finding is consistent with prior research. Luo and colleagues [9] examined risk factors for respiratory dysfunction (defined as >72 hours of mechanical ventilation or the need for reintubation for hypoxemia) in 196 patients undergoing repair of type A aortic dissection with hypothermic (18°C–25°C) circulatory arrest and found longer duration of circulatory arrest to be an independent risk factor for postoperative pulmonary dysfunction.

The association between age and PPRS is not surprising as changes in the pulmonary system seen with aging are well established [15–18]. Specifically, with age the elasticity of the lungs decreases, intercostal muscle mass is reduced and gas exchange surfaces lessen. Dysregulation of the innate immune system with aging leads to persistent respiratory tract inflammation, which likely contributes to pulmonary dysfunction [19]. Older patients also have a decreased cough reflex [20], meaning that they are less able to clear secretions, further compromising lung function. Finally, there are numerous age-related comorbidities that may affect a patient's overall heath state, thereby decreasing the ability to tolerate the stress of surgery.

The current study also identified diabetes as a marginal, but biologically plausible, risk factor for PPRS. Pulmonary dysfunction has been observed in patients with both type 1 and type 2 diabetes, with reduction in forced vital capacity, forced expiratory volume in 1 second, and diffusion capacity [21–25]. These changes are thought to be due to microvascular changes in the pulmonary capillary beds, reduced elasticity of the lungs due to glycosylation of lung elastin, and autonomic neuropathy affecting the phrenic nerves [21,26], all of which may account for the observed increased incidence of PPRS in diabetic patients undergoing proximal thoracic aortic surgery.

The number of blood products transfused was associated with PPRS in our cohort, which is also consistent with existing literature. In an analysis of more than 16000 patients undergoing CABG and/or cardiac valve surgery, transfusion recipients had increased pulmonary complications including longer intubation times, higher reintubation rates, and more frequent acute respiratory distress syndrome [2]. Another study of nearly 17000 isolated CABG patients demonstrated that transfusion of as few as 1 or 2 units of red blood cells was associated with increased morbidity and mortality, including prolonged ventilator requirement [27]. Our findings further emphasize that blood products should be used judiciously after cardiac surgery.

Other previously identified risk factors for pulmonary complications after cardiac surgery in the published literature have included decreased left ventricular ejection fraction, congestive heart failure, chronic obstructive pulmonary disease (COPD), and current or former smoking history [1,13,28–31]. In the current study, COPD and smoking were associated with PPRS in univariate analysis, but neither remained significant in the multivariable model, possibly due to colinearity with other variables in the model. Likewise, we did not identify left ventricular ejection fraction or congestive heart failure as risk factors, likely due to the low incidence of these comorbidities in the aortic population studied.

The current study demonstrated reduced survival among patients requiring PPRS, particularly within the first year. This finding is consistent with Lou et al [7], who demonstrated increased in-hospital mortality for patients with respiratory dysfunction vs those without (23.1% vs 7.6%, $P = .025$). Unique to the current study, however, was the finding that patients who required PPRS were more likely to be discharged to other than home. Prolonged institutional care can add considerable cost and burden to patients and their families. The possibility of such need, in addition to decreased survival, should be included in any discussion regarding the risks and benefits of proximal thoracic aortic surgery, especially with patients at risk for requiring PPRS.

There are limitations of this study that are worth noting. This is a single-institution, retrospective study, with all of the inherent biases of such a study. The nature of the study also might limit the ability to generalize the outcomes to other centers. Furthermore, this study does not suggest the underlying etiology of PPRS. Failure of PPRS patients to quickly wean from support is likely due to some degree of respiratory failure, acute lung injury, or hypoxia. However, PPRS cannot be linked to one specific factor. Nevertheless, PPRS is clinically-significant in terms of both resource use (ventilator days, tracheostomy, home oxygen) as well as long-term survival.

In summary, pulmonary dysfunction requiring PPRS is common after proximal thoracic aortic surgery and is associated with worse outcomes. Age, diabetes, history of stroke, preoperative creatinine, ASA class 4, redo-sternotomy, total arch replacement, and blood product transfusion are all associated with the need for PPRS, whereas the use of DHCA is not. Knowledge of these risk factors for PPRS in patients undergoing thoracic aortic surgery with DHCA may allow for optimization of perioperative clinical management strategies and improve preoperative risk stratification. Perceived increased risk of PPRS should not lead to avoidance of DHCA as an adjunctive measure when performing proximal thoracic aortic surgery.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jcrc.2015.10.021.

Abbreviations

ASA	American Society of Anesthesiologists
BMI	body mass index
CHF	congestive heart failure
COPD	chronic obstructive pulmonary disease
CPB	cardiopulmonary bypass
DHCA	deep hypothermic circulatory arrest
GERD	gastroesophageal reflux disease
IQR	interquartile range
LOS	length of stay
LVEF	left ventricular ejection fraction
MI	myocardial infarction
PPRS	prolonged postoperative respiratory support

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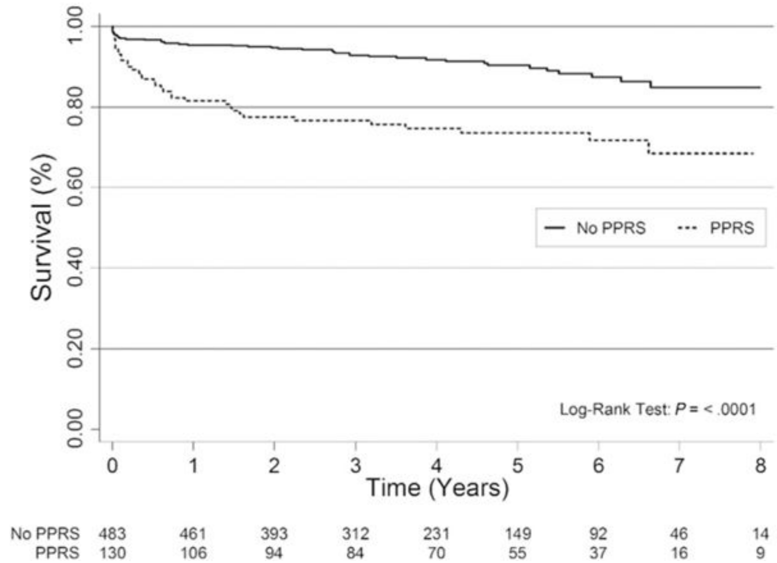

Fig. 1.

Kaplan-Meier curves demonstrating long-term survival of patients requiring PPRS vs those patients who did not.

Table 1

Patient demographics (n = 613)

Variables	
Age (y)	56.3 ± 14.4
Male sex	58.7% (360)
White	74.9% (459)
BMI (kg/m^2)	28.6 ± 8.0
Smoker	44.7% (274)
COPD	12.9% (79)
CHF	8.8% (54)
LVEF (%)	52.8 ± 6.2
Hypertension	76.0% (466)
Preop diuretic	29.2% (179)
Prior MI	7.3% (45)
Diabetes	8.3% (51)
History of stroke	7.3% (45)
GERD	21.2% (130)
Alcohol abuse	6.2% (38)
Steroid use	2.3% (14)
Preop creatinine (mg/dL)	1.0 (0.9, 1.2)
Preop hemoglobin (g/dL)	13.3 ± 2.3
Nonelective case status	
Urgent	13.4% (82)
Emergent	13.2% (81)
ASA class 4	32.8% (201)
Redo-sternotomy	24.3% (149)
Concurrent procedure	31.6% (194)
Concurrent CABG	17.1 % (105)
CPB time (min)	217.1 ± 103.4
Aortic cross-clamp time (min)	139.1 ± 53.5
DHCA use	78.0% (478)

BMI indicates body mass index; CHF, congestive heart failure; GERD, gastroesophageal reflux disease; LVEF, left ventricular ejection fraction; MI, myocardial infarction, preop, preoperative.

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Table 2

PPRS in proximal aortic surgery

No PPRS	483 (78.8%)
PPRS[a]	130 (21.2%)
Ventilator support >1 d	39 (6.4%)
Supplemental O_2 >2 d	112 (18.3%)
New home O_2 requirement	12 (1.2%)

[a]Note that some patients with PPRS fulfilled multiple criteria and total number of patients with each criterion is listed.

Table 3

Univariate predictors of PPRS in proximal aortic surgery

Variables	No PPRS (n = 483)	PPRS (n = 130)	*P*
Age (y)	55.5 ± 14.1	59.5 ± 15.0	.005
Male sex	57.8% (279)	62.3% (81)	.35
White	76.2% (368)	70.0% (91)	.15
BMI (kg/m^2)	28.3 ± 6.0	29.4 ± 12.9	.17
Smoker	41.6% (201)	56.2% (73)	.003
COPD	11.0% (53)	20.0% (26)	.006
CHF	8.1% (39)	11.5% (15)	.22
LVEF (%)	52.8 ± 6.1	52.4 ± 6.6	.56
Hypertension	73.9% (357)	83.9% (109)	.019
Preop diuretic	28.8% (139)	31.0% (40)	.63
Prior MI	6.2% (30)	11.5% (15)	.039
Diabetes	7.0% (34)	13.1% (17)	.027
History of stroke	5.0% (24)	16.2% (21)	<.0001
GERD	19.3% (93)	28.5% (37)	.023
Alcohol abuse	6.0% (29)	6.9% (9)	.70
Steroid use	2.1% (10)	3.1% (4)	.50
Preop creatinine (mg/dL)	1.0 (0.8,1.2)	1.0 (0.9,1.3)	.007
Preop hemoglobin (g/dL)	13.3 ± 1.9	12.8 ± 2.1	.018
Nonelective case status			<.0001
Urgent	13.0% (63)	14.6% (19)	
Emergent	10.4% (50)	23.9% (31)	
ASA class 4	28.0% (135)	50.8% (66)	<.0001
Redo sternotomy	21.3% (103)	35.4% (46)	.001
Concurrent procedure	28.2% (136)	44.6% (58)	<.0001
Concurrent CABG	14.7% (71)	26.2% (34)	.002
CPB time (min)	213.2 ± 108.0	231.7 ± 81.9	.08
Aortic cross-clamp time (min)	137.7 ± 40.2	144.2 ± 87.1	.23
DHCA use	78.3% (378)	76.9% (100)	.74

BMI indicates body mass index; CHF, congestive heart failure; GERD, gastroesophageal reflux disease; LVEF, left ventricular ejection fraction; MI, myocardial infarction; preop, preoperative.

Table 4

Multivariate model for PPRS

Variable	OR (95% CI)	*P*
Age (per 5-y increase)	1.16 (1.04–1.29)	.009
Diabetes	1.99 (1.01–3.95)	.048
History of stroke	2.79 (1.41–5.53)	.003
Preoperative creatinine (per mg/dL)	1.39 (1.06–1.82)	.017
ASA class 4	1.95 (1.25–3.03)	.003
Redo-sternotomy	1.77 (1.10–2.86)	.019
Total arch replacement	3.02 (1.47–6.21)	.003
Transfusion requirement within first 72 h (per unit)[a]	1.03 (1.01–1.05)	.003

[a]Tested individually, then added to the rest of the model.

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Table 5

Postoperative outcomes

Outcome	No PPRS (n = 483)	PPRS (n = 130)	*P*
Length of stay (d)	5 (5–7)	11 (7–19)	<.0001
Discharge to other than home	27 (5.6%)	35 (27.9%)	<.0001
In-hospital death	13 (2.7%)	11 (8.5%)	.003

Data presented as either median (IQR) or n (%).