

**Original
Article**

Respiratory Failure after Open Descending Aortic Aneurysm Repair: Risk Factors and Outcomes

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Purpose: This study was conducted to identify predictors of respiratory failure after open repair of descending thoracic aortic aneurysm (DTAA), and to identify any relationship between respiratory failure and long-term survival.

Methods: A total of 75 patients undergoing elective open DTAA repair at the Shiga University of Medical Science Hospital were included in the study. Univariate and multivariate logistic regression analyses were performed to assess the odds ratios for incident postoperative respiratory failure after open DTAA repair. Survival over time was estimated by the Kaplan–Meier method.

Results: Respiratory failure, defined as ventilation dependence for longer than 48 hours, occurred in 11 patients (14.7%). Independent predictors of respiratory failure after DTAA included prolonged operation time and reduced preoperative forced expiratory volume in 1 second/forced vital capacity $\times 100$ (FEV₁%). In-hospital mortality was higher ($p = 0.020$) among patients with respiratory failure (18.2% of those who suffered respiratory failure) than among those without (0%). The survival rates at 8 years were significantly lower ($p = 0.010$) in the respiratory failure group (at 44.2%) than in the group without respiratory failure (at 89.0%).

Conclusion: Lower FEV₁% and longer operation time were risk factors of postoperative respiratory failure after open repair of DTAA, which in turn is associated with significantly reduced long-term survival.

Keywords: descending thoracic aortic aneurysm, open repair, respiratory failure, preoperative pulmonary function, aortic aneurysm

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Introduction

Although patients requiring thoracic aneurysm repair are increasingly being treated with thoracic endovascular aortic repair (TEVAR), there are many patients who will require open repair for reasons of anatomy, age, or the underlying etiology of their disease. Traditionally, open repair for descending thoracic aortic aneurysms (DTAAs) has been done through left thoracotomy or thoracoabdominal incision. Because such repair involves single-lung ventilation for several hours, these patients

are particularly prone to developing respiratory complications and even respiratory failure.

Postoperative respiratory failure is among the most serious of the postoperative pulmonary complications. The deleterious influence of pulmonary disease on outcome after open thoracoabdominal aortic aneurysm (TAAA) repair was explored in a previous era.¹⁾ However, there is limited information concerning the impact of respiratory function in relation to open DTAA repair. This study was conducted to identify predictors of respiratory failure after open repair of DTAA, and to identify any relationship between respiratory failure and long-term survival.

Materials and Methods

Patients and study design

Between January 2002 and May 2019, a total of 132 patients underwent elective and isolated DTAA repair at the Shiga University of Medical Science. Of 132 patients, 51 (38.6%) who underwent endovascular aortic repair were excluded. For the present analysis, 75 patients were included who had preoperative respiratory function evaluated by spirometry (92.6% of elective and isolated cases). All these aortic surgeries were done by two surgeons (T.S. and T.A.). Indications for surgical interventions included descending aortic diameter exceeding 55 mm, rapid dilatation of the aorta (>5 mm/6 months), infection (bronchial/esophageal fistula/stent graft infection). Institutional Review Board approval was obtained (R2019-191) and the need for consent was waived because the study design was retrospective and relevant identifiers were stripped from the data.

Surgical technique

After induction of general anesthesia, the patient was intubated with a double-lumen endotracheal tube to enable single right-lung ventilation. All operations were done with the patient in the right lateral decubitus position with the pelvis rotated to the left to allow easy access to the left femoral vessels. We do not routinely use cerebrospinal fluid (CSF) drainage, to avoid potential complications of CSF drain insertion. The aorta was accessed through a left thoracoabdominal incision. Resection of adjacent ribs was performed when necessary. Distal aortic perfusion was achieved with femoral–femoral bypass. Hypothermic circulatory arrest (HCA) was used in 27 (36%) patients and was effected by perfusion cooling. The median cerebral ischemia time during HCA was

41 minutes (interquartile range: 24–50) at a median core temperature of 21.0°C (interquartile range: 20.2–22.0). The decision to utilize HCA was prompted by technical considerations, often involving the feasibility and safety of clamping the aorta proximal to the repair. Partial cardiopulmonary bypass without HCA was used in 48 (64%) patients. Core temperature was targeted at 32°C or above (permissive mild hypothermia). In mild hypothermia, we used the segmental clamp technique to reduce spinal cord ischemic time and to close the patient intercostals, which should not be reconstructed immediately after opening the aorta. When internal costal artery (ICA) reconstruction was necessary, the ICAs were occluded with an occlusion catheter to prevent spinal cord steal. The dissection flap extending beyond the distal anastomosis was fenestrated to allow blood flow in both the true and false lumen.

Postoperative respiratory management

Postoperatively, the double-lumen tube is routinely exchanged for a single-lumen endotracheal tube. We aim to extubate the patients within the first 24 hours and maintain a reverse Trendelenburg position. Chest physiotherapy and nebulizer treatments are routine in the postoperative protocol. In general, if a patient could not be safely separated from the ventilator by approximately 7 days after surgery, a tracheostomy was performed by an open technique.

Definitions

Preoperative hypertension was defined as history of taking antihypertensive medication and/or receiving nutrition or physical therapy based on the diagnosis of hypertension. Postoperative respiratory failure was defined as ventilator dependence for more than 48 hours in accordance with a previous study of patients undergoing thoracoabdominal aortic aneurysm repair.¹⁾ This included reintubation and occasional need for tracheostomy.

Statistical analysis

Categorical variables are described in numbers and percentages. All reported continuous variables were not normally distributed and therefore were described as medians with interquartile range. Categorical variables were analyzed using the χ^2 test or Fisher's exact test and continuous variables using the t-test or nonparametric Mann–Whitney U test as appropriate. Multivariate logistic regression modeling was used to determine independent perioperative predictors of respiratory failure after

descending aortic repair. Variables that reached $p < 0.050$ in the univariate analysis or that were considered clinically important were entered into multivariate logistic regression analysis. For reliable analysis, we required at least 10 events of the primary outcome measure per variate.²⁾ Multivariate logistic regression was used after controlling simultaneously for potential confounders. Cox proportional hazard regression was performed for the analysis of late mortality. Variables that reached $p < 0.050$ in the univariate analysis or that were considered clinically important were entered into the multivariate model. Survival over time was estimated by the Kaplan–Meier method and compared in a log-rank test. Results were considered statistically significant at a level of $p < 0.050$. Data were extracted into a Microsoft Excel spreadsheet (Microsoft Corp, Redmond, WA, USA) and analyzed in SPSS Statistics 25.0 software (SPSS Inc., Chicago, IL, USA) for Windows (Microsoft Corp).

Results

Early outcomes

Respiratory failure requiring ventilation for longer than 48 hours occurred in 11 of 75 patients (14.7%). Preoperative characteristics are reviewed in **Table 1**. Patients with such respiratory failure were less likely to have shown hypertension (36.3% vs 82.8%; $p = 0.001$) than were the patients without respiratory failure. Although there was no statistically significant difference, there were trends toward lower forced expiratory volume in 1 second/forced vital capacity $\times 100$ (FEV₁%) and vital capacity in the respiratory failure group than in the group without respiratory failure.

Operative details are shown in **Table 1**. Patients with respiratory failure had longer operation times (median operation time, 327 minutes [interquartile range: 294–398] vs 252 minutes [interquartile range: 193–296]; $p = 0.001$), longer bypass times (median bypass time, 173 minutes [interquartile range: 114–198] vs 79 minutes [interquartile range: 51–138]; $p = 0.004$), were more likely to have undergone circulatory arrest (63.6% vs 31.3%; $p = 0.039$), and required more transfusions (100% vs 59.4%; $p = 0.009$).

Early outcomes are shown in **Table 2**. There was zero 30-day mortality in both groups. In-hospital mortality was higher in patients with respiratory failure ($n = 2$, 18.2%) than in those without ($n = 0$, 0%; $p = 0.020$). One patient, an 82-year-old man, had previously undergone a total arch replacement. He was found to have a distal

anastomotic pseudoaneurysm involving the composite graft and a separate descending aortic aneurysm. After the open descending aortic aneurysm repair, he was also found to have an aorto-esophageal fistula. Mediastinitis developed and he subsequently died. A second patient, a 56-year-old man, had previously undergone replacement of his ascending aorta for acute type A dissection. Nine years later, he underwent open descending aortic repair for chronic post-dissection aneurysm. A significant amount of thrombus was found inside the aneurysm. Visceral arterial embolism developed postoperatively, and subsequently he died. Most respiratory complications were significantly more common in patients with respiratory failure than in those without. The length of stay was longer in patients with respiratory failure (median length of stay, 50 days [interquartile range: 31–137] than in those without (median length of stay, 22 days [interquartile range: 17–34]; $p = 0.001$).

Univariate and multivariate logistic regression analyses of the incidence of postoperative respiratory failure in relation to baseline and operative values is shown in **Table 3**. In univariate models, hypertension was associated with a decreased risk of postoperative respiratory failure (odds ratio: 0.12; CI: 0.03–0.48; $p = 0.003$). On the other hand, longer operation time (odds ratio: 1.15; CI: 1.05–1.25; $p = 0.003$) and use of HCA (odds ratio: 3.85; CI: 1.01–14.7; $p = 0.048$) were associated with increased risks of postoperative respiratory failure. In multivariate models, hypertension was also associated with a decreased risk of postoperative respiratory failure (odds ratio: 0.06; CI: 0.01–0.57; $p = 0.014$). Lower FEV₁% (odds ratio: 3.69; CI: 1.24–11.0; $p = 0.019$) and longer operation time (odds ratio: 1.18; CI: 1.03–1.35; $p = 0.017$) were statistically significant risk factors of postoperative respiratory failure. These variables jointly yielded an area under the curve (AUC) of 0.937.

Long-term outcomes

The median follow-up durations were 1.7 years (interquartile range: 0.5–5.5] in the respiratory failure group and 3.0 years (interquartile range: 1.0–7.5] in the group without respiratory failure. In multivariate analysis, included variables were age (per year); hypertension; smoking history; vital capacity (10% decrement); FEV₁% (10% decrement); operation time (10-minute increments); HCA; postoperative respiratory failure. As a result, age (hazard ratio: 1.08; CI: 1.01–1.16; $p = 0.032$) and postoperative respiratory failure (hazard ratio:

Table 1 Preoperative and intraoperative patient demographics

	All (n = 75)	Respiratory failure (n = 11)	No respiratory failure (n = 64)	p value
Preoperative				
Age, years	69 [57–75]	62 [53–80]	69 [58–75]	0.595
Age ≥70 years	32 (42.6)	3 (27.2)	29 (45.3)	0.263
Female gender	14 (18.6)	2 (18.1)	12 (18.7)	0.964
Body mass index, kg/m ²	23.3 [20.5–26.0]	22.5 [20.5–26.0]	23.4 [20.5–25.9]	0.784
Smoking history	54 (72.0)	9 (81.8)	45 (70.3)	0.432
Diabetes mellitus	12 (16.0)	3 (27.2)	9 (14.0)	0.269
Hypertension	57 (76.0)	4 (36.3)	53 (82.8)	0.001
Serum creatinine, mg/dL	0.93 [0.77–1.29]	0.79 [0.69–1.02]	0.99 [0.78–1.31]	0.123
FEV ₁ %, %	71.6 [64.8–76.4]	70.3 [58.9–74.5]	71.6 [65.6–76.7]	0.154
Vital capacity, %	96.2 [83.4–112]	85.9 [82.1–116]	97.0 [84.6–112]	0.150
Marfan syndrome	4 (5.3)	1 (9.1)	3 (4.6)	0.477
Cause				
Degenerative aneurysm	29 (38.7)	2 (18.2)	27 (42.1)	0.131
Chronic post-dissection aneurysm	41 (54.7)	7 (63.6)	34 (53.1)	0.518
Pseudoaneurysm	3 (4.0)	1 (9.1)	2 (3.1)	0.383
Re-expansion after TEVAR	2 (2.7)	1 (9.1)	1 (1.6)	0.274
Proximal extent of aortic replacement				
Zone 3	27 (36.0)	3 (27.2)	24 (37.5)	0.514
Zone 4	48 (64.0)	8 (72.7)	40 (62.5)	0.514
T4	23 (30.7)	6 (54.5)	17 (26.6)	0.063
T5	7 (9.3)	1 (9.1)	6 (9.4)	0.976
T6	5 (6.7)	0 (0)	5 (7.8)	0.442
T7	5 (6.7)	0 (0)	5 (7.8)	0.442
T8	3 (4.0)	0 (0)	3 (4.7)	0.617
T9	2 (2.7)	1 (9.1)	1 (1.6)	0.274
T10	3 (4.0)	0 (0)	3 (4.7)	0.617
EuroSCORE II, %	3.39 [2.11–6.42]	3.76 [2.88–6.42]	3.18 [2.08–6.35]	0.574
Previous aortic repair				
Open surgery	45	7	8	
Aortic root	1 (1.3)	0 (0)	1 (1.5)	0.853
Ascending aorta	13 (17.3)	3 (27.2)	10 (15.6)	0.346
Arch	19 (25.3)	4 (36.3)	15 (23.4)	0.362
Descending aorta	3 (4.0)	0 (0)	3 (4.7)	0.617
Abdominal aorta	9 (12.0)	0 (0)	9 (14.0)	0.184
Endovascular repair	3	1	2	
Descending aorta	3 (6.0)	1 (9.1)	2 (3.1)	0.383
Intraoperative				
Operation time, minutes	266 [201–323]	327 [294–358]	252 [193–296]	0.001
Bypass time, minutes	88 [54–146]	173 [114–198]	79 [51–138]	0.004
Hypothermic circulatory arrest	27 (36.0)	7 (63.6)	20 (31.3)	0.039
Intercostal arteries reconstruction	5 (6.7)	0 (0)	5 (7.8)	0.442
Transfusion	49 (65.3)	11 (100)	38 (59.4)	0.009

Categorical data are presented as n (%) and continuous data as median [interquartile range]. EuroSCORE: European System for Cardiac Operative Risk Evaluation; FEV₁% = (forced expiratory volume in 1 second/forced vital capacity) × 100; TEVAR: thoracic endovascular aortic repair

5.79; CI: 1.58–21.2; $p = 0.008$) emerged as significant independent predictors of long-term survival (**Table 4**). The actual survival rate at 8 years was 44.2% in the respiratory failure group and 89.0% in the group without respiratory failure, which was significantly different ($p = 0.010$, **Fig. 1**).

Discussion

Whereas respiratory failure after TAAA repair occurs in 20%–43% of patients,^{1,3-5} such information is scarce in open repair for DTAAAs isolated to the chest. In our series, 14.7% of patients developed respiratory failure;

Table 2 Early outcomes

	All (n = 75)	Respiratory failure (n = 11)	No respiratory failure (n = 64)	p value
30-day mortality	0 (0)	0 (0)	0 (0)	–
In-hospital mortality	2 (2.7)	2 (18.2)	0 (0)	0.020
Tracheostomy	5 (6.7)	5 (45.5)	0 (0)	<0.001
Pneumonia	4 (5.3)	3 (27.3)	1 (1.6)	0.009
Pleural effusion requiring drainage	22 (29.3)	8 (72.7)	14 (21.9)	0.001
Chylothorax	6 (8.0)	2 (18.2)	4 (6.3)	0.178
Reintubation	5 (6.7)	4 (36.4)	1 (1.6)	0.001
Stroke	5 (6.7)	2 (18.2)	3 (4.7)	0.153
Paraplegia or paraparesis	3 (4.0)	1 (9.1)	2 (3.1)	0.383
Bleeding necessitating reoperation	5 (6.7)	1 (9.1)	4 (6.3)	0.558
Wound dehiscence	10 (13.3)	2 (18.2)	8 (12.5)	0.609
Wound infection	4 (5.3)	1 (9.1)	3 (4.7)	0.477
Length of stay, days	23 [17–39]	50 [31–137]	22 [17–34]	0.001

Categorical data are presented as n (%) and continuous data as median [interquartile range].

Table 3 Univariate and multivariate models of the incidence of postoperative respiratory failure in relation to baseline and operative value

Variable	Univariate model		Multivariate model	
	Odds ratio (95% CI)	p value	Odds ratio (95% CI)	p value
Age, years (10-year increments)	0.82 (0.49–1.38)	0.453	0.70 (0.33–1.48)	0.352
Sex				
Female	1 [Reference]			
Male	1.04 (0.20–5.44)	0.964		
Body mass index, kg/m ²	1.07 (0.91–1.25)	0.416		
Diabetes mellitus				
No	1 [Reference]			
Yes	2.29 (0.51–10.2)	0.279		
Hypertension				
No	1 [Reference]		1 [Reference]	
Yes	0.12 (0.03–0.48)	0.003	0.06 (0.01–0.57)	0.014
Dyslipidemia				
No	1 [Reference]			
Yes	0.19 (0.02–1.59)	0.126		
Previous aortic repair				
No	1 [Reference]			
Yes	1.86 (0.50–6.99)	0.357		
Marfan syndrome				
No	1 [Reference]			
Yes	2.03 (0.19–21.5)	0.556		
Preoperative Serum creatinine, mg/dL	0.69 (0.20–2.36)	0.552		
EuroSCORE II, %	1.02 (0.88–1.18)	0.773		
Smoking history				
No	1 [Reference]		1 [Reference]	
Yes	1.90 (0.38–9.63)	0.438	15.7 (0.89–278)	0.060
Vital capacity, % (10% decrement)	1.26 (0.90–1.77)	0.181	1.45 (0.92–2.30)	0.113
FEV ₁ , % (10% decrement)	1.55 (0.88–2.71)	0.129	3.69 (1.24–11.0)	0.019
Operation time, minutes (10-minute increments)	1.15 (1.05–1.25)	0.003	1.18 (1.03–1.35)	0.017
Hypothermic circulatory arrest				
No	1 [Reference]		1 [Reference]	
Yes	3.85 (1.01–14.7)	0.048	1.46 (0.18–11.9)	0.723

EuroSCORE: European System for Cardiac Operative Risk Evaluation; FEV₁%, (forced expiratory volume in 1 second/forced vital capacity) × 100

Table 4 Multivariate analysis of risk factors for long-term survival

Variable	Hazard ratio (95% CI)	<i>p</i> value
Age, years (per year)	1.08 (1.01–1.16)	0.032
Hypertension	0.70 (0.09–5.80)	0.745
Smoking history	1.31 (0.20–8.57)	0.781
Vital capacity, % (10% decrement)	1.05 (0.73–1.51)	0.786
FEV ₁ %, % (10% decrement)	1.04 (0.97–1.12)	0.299
Operation time, minutes (10-minute increments)	1.00 (0.99–1.01)	0.656
Hypothermic circulatory arrest	2.67 (0.37–19.1)	0.328
Postoperative respiratory failure	5.79 (1.58–21.2)	0.008

FEV₁%: (forced expiratory volume in 1 second/forced vital capacity) × 100

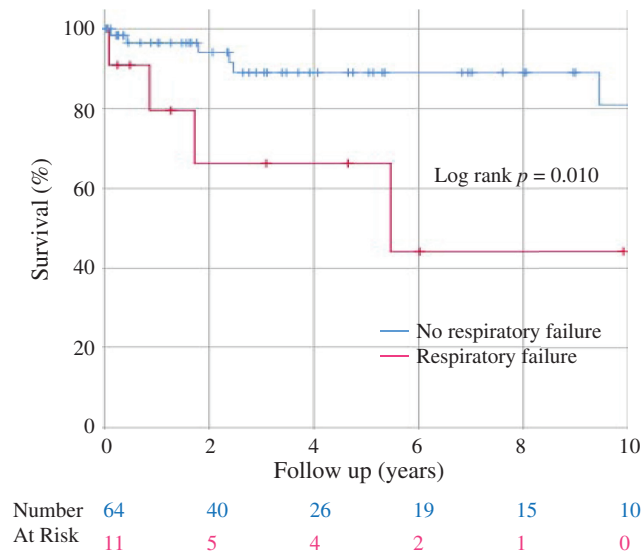


Fig. 1 Kaplan–Meier curves of long-term survival for 75 patients who underwent descending thoracic aortic aneurysm repair, stratified by whether patients developed respiratory failure after repair (*n* = 11) or not (*n* = 64).

this is a lower incidence than in previous findings including open TAAA repair. In addition, univariate and multivariate analyses showed that longer operation time was associated with an increased risk of postoperative respiratory failure, and HCA was also associated with increased risks of postoperative respiratory failure in univariate models. These findings suggest that surgical invasiveness is a risk factor for respiratory failure after open DTAA repair.

Although the risk of respiratory failure was mostly dependent on operative factors, reduced preoperative FEV₁% was a statistically significant risk factor for postoperative respiratory failure in multivariate models. Girardi and colleagues have reported preoperative FEV₁% < 50% as predictive of increased respiratory failure, tracheostomy, and operative mortality in patients

undergoing open DTAA or TAAA repair.⁶ With an aging population and an overall increase in the prevalence of chronic obstructive pulmonary disease (COPD), surgeons performing DTAA repair are evaluating increasing numbers of patients with compromised pulmonary function. Upwards of 25% of a large, contemporary group of patients undergoing open DTAA or TAAA repair had advanced COPD.⁷ In patients with significant pulmonary dysfunction, there may be some distinct advantage of endovascular repair over open repair. The Gore TAG Investigators reported a substantial reduction in postoperative respiratory failure when comparing TEVAR with a historical group of controls undergoing open DTAA repair (4% vs 20%).⁸ Similarly, Tanaka and colleagues found that TEVAR had lower risk of postoperative respiratory failure, compared with open DTAA

repair in an observational study (10% vs 34%).⁹⁾ However, TEVAR is still associated with significant complications and a relatively high incidence of endoleaks and repeat interventions that may affect its long-term durability.¹⁰⁾ We need to select the procedure for DTAA carefully considering these factors.

Interestingly, preoperative hypertension was significantly more common in the group without respiratory failure. Univariate and multivariate analyses also showed that preoperative hypertension was associated with a decreased risk of postoperative respiratory failure. Griep and colleagues found that a history of hypertension was present in most patients with aneurysms, and it was widely recognized that hypertension, especially diastolic hypertension, was highly correlated with the initial development of aneurysms.¹¹⁾ They also found significantly more rapid growth of aortic aneurysms in smokers and patients with COPD.¹¹⁾ In our series, there were trends toward lower FEV₁% and more smokers in the respiratory failure group than in the group without respiratory failure. We simply defined all patients receiving antihypertensive treatment as having, or having had, preoperative hypertension, but most such people had regular care, and so were likely to have more-or-less controlled hypertension, and to receive anti-smoking advice and possibly meticulous anti-COPD care where relevant. Therefore, the appearance of association between preoperative hypertension and decreased risk of postoperative respiratory failure may have been an artefact of selection.

Unsurprisingly, our patients with respiratory failure had significantly higher in-hospital mortality and longer hospital stay than patients without respiratory failure. Furthermore, survival estimates at 8 years were significantly lower in the respiratory failure group than in the group without respiratory failure. Several studies have identified early and mid-term consequences of prolonged ventilation after cardiac surgery.^{12,13)} These studies found that prolonged mechanical ventilation was associated with reduced early and mid-term survival; this is consistent with our findings.

This study had certain limitations. It was retrospective, from a single center, and observational. The retrospective nature along with the relatively long time period this study covers may have involved changes in clinical practices and processes that might have affected the outcomes. Also, the sample size was small, with only 75 patients, of whom only 11 suffered respiratory failure.

Conclusion

Lower FEV₁% and longer operation time were risk factors for postoperative respiratory failure. Moreover, patients with postoperative respiratory failure had an increased incidence of in-hospital mortality and markedly poorer long-term survival. Endovascular repair (including total arch replacement and subsequent TEVAR, or fenestrated or branched stent placement) may be more suitable therapeutic option in high-risk patients.

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Disclosure Statement

The authors have declared that no conflict of interest exists.

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