Heart Surgery Forum 2025; 28(2): E166–E174
doi: 10.59958/hsf.8253 https://journal.hsforum.com/

Article

Analysis of Factors Affecting Limb Function Recovery Following Surgery for Acute Type A Aortic Dissection Complicated by Lower Extremity Malperfusion: A Retrospective Study

Ping Zhang[1,†], Jiajia Ban[1,†], Mengya Wu[1], Yuexiu Hu[1], Haitao Zhang[1], Qing Zhou[1], Xiaoli Xie[1,*], Yunyan Su[1,*]

[1]Department of Cardiothoracic Surgery, Nanjing Drum Tower Hospital, Affiliated Hospital of Medical School, Nanjing University, 210008 Nanjing, Jiangsu, China

*Correspondence: 65056042@qq.com (Xiaoli Xie); sumaomao66@163.com (Yunyan Su)

[†]These authors contributed equally.

Submitted: 24 November 2024 Revised: 12 January 2025 Accepted: 20 January 2025 Published: 21 February 2025

Abstract

Background: This study aims to analyze the clinical characteristics and factors influencing postoperative limb function recovery in patients with acute type A aortic dissection (ATAAD) complicated by lower extremity malperfusion (LEM). The objective is to accurately assess preoperative conditions, identify and manage risk factors, improve surgical techniques, and offer insights to enhance the recovery rate of LEM following surgery. **Methods**: This retrospective study included 131 patients with ATAAD complicated by LEM, admitted to the Department of Cardiothoracic Surgery at Nanjing Drum Tower Hospital between January 2013 and June 2019. Based on the resolution of lower extremity malperfusion postoperatively, patients were divided into a recovery group (n = 80) and a non-recovery group (n = 51). The preoperative limb status and general condition of both groups were evaluated, and factors influencing limb function recovery were analyzed using univariate and multivariate logistic regression. **Results**: Univariate analysis revealed statistically significant differences between the recovery and non-recovery groups for various variables. These included ischemic symptoms (odds ratio [OR] = 3.841, 95% confidence interval [CI] 1.850–8.197, $p < 0.001$), paresthesia (OR = 2.197, 95% CI 1.080–4.538, $p = 0.031$), decreased muscle strength (OR = 2.594, 95% CI 1.203–5.688, $p = 0.016$), decreased skin temperature (OR = 2.475, 95% CI 1.205–5.162, $p = 0.014$), non-detectable limb blood pressure (OR = 2.667, 95% CI 1.270–5.692, $p = 0.010$), prolonged cardiopulmonary bypass time (OR = 1.008, 95% CI 1.003–1.014, $p = 0.002$), prolonged aortic occlusion time (OR = 1.008, 95% CI 1.001–1.014, $p = 0.018$), and the requirement for continuous renal replacement therapy (CRRT) (OR = 8.095, 95% CI 3.620–19.165, $p < 0.001$). There were no significant differences between the groups in terms of gender, age, body mass index (BMI), absence of limb numbness or pain, skin pallor or mottling, absence of femoral or dorsalis pedis pulses, or non-detectable lower limb blood pressure ($p > 0.05$). Multivariate logistic regression identified ischemic symptoms (OR = 4.519, 95% CI 1.910–11.320, $p = 0.001$), non-measurable blood pressure (OR = 2.720, 95% CI 1.093–6.996, $p = 0.033$), and prolonged cardiopulmonary bypass time (OR = 1.018, 95% CI 1.006–1.034, $p = 0.011$) as independent early predictors of failure to recover limb function in patients with ATAAD. **Conclusion**: In ATAAD patients presenting with lower extremity ischemia at admission, healthcare providers should maintain heightened vigilance for postoperative ischemia, especially in cases with bilateral limb ischemia and non-measurable blood pressure. Early identification of these risk factors may contribute to enhancing postoperative outcomes.

Keywords

acute type A aortic dissection; lower extremity malperfusion; limb function recovery; influencing factors

Introduction

Acute type A aortic dissection (ATAAD) is characterized by rapid progression, widespread implications, and elevated susceptibility to numerous complications, rendering it among the most critical conditions in cardiovascular surgery. Without surgical intervention, the mortality rate for ATAAD can reach up to 33% within the initial 24 hours, with a subsequent increase of 1–2% per hour. Alarmingly, more than 70% of patients may not survive beyond the first week. Urgent surgical intervention remains the primary treatment option for ATAAD [1–3]. Despite advancements in diagnostic techniques and surgical methods, including improvements in anesthesia, cardiopulmonary bypass, and organ-protection strategies, the persistence of elevated postoperative mortality and complication rates is predominantly attributed to the severe preoperative status of these individuals [4,5].

A significant determinant impacting the prognosis of ATAAD surgery is malperfusion syndrome (MPS), characterized by inadequate blood flow to one or more organs or limbs. Approximately 33% of patients with ATAAD encounter some form of malperfusion, with the lower extremities being the most commonly involved [6]. Lower limb malperfusion (LLM) is the most frequent type of extremity malperfusion. The presence of MPS among ATAAD patients is an independent risk factor for early postoperative mortality and unfavorable outcomes [6,7]. Studies have shown that the mortality rate in ATAAD patients with MPS ranges from 29% to 89%, compared to 5% to 23% in those without MPS, indicating a 10- to 30-fold increase in mortality [6]. Specifically, LLM can lead to severe complications such as muscle necrosis, compartment syndrome, and limb amputation, heightening the susceptibility to multiple organ dysfunction syndrome and mortality [8–10].

In ATAAD patients with LLM, inadequate blood flow to the lower extremities may result from the dissection flap extending into the iliac or femoral arteries, leading to a reduction or complete obstruction of distal perfusion [11]. This ischemia not only threatens limb viability but can also cause irreversible damage to muscles and nerves, complicating postoperative recovery. Early identification and intervention are critical to restoring perfusion and preventing long-term disability. However, despite advancements in surgical techniques and postoperative management, a significant proportion of patients with preoperative LLM continue to experience persistent malperfusion postoperatively, severely impacting both their prognosis and quality of life.

Several studies have explored various strategies to manage ATAAD with LLM, encompassing both endovascular and open surgical interventions designed to restoring distal perfusion. While these strategies have contributed to reductions in overall mortality, postoperative outcomes for limb function recovery remain suboptimal in certain patients. Sustained postoperative malperfusion of the limbs can prolong recovery durations, elevate the incidence of complications like limb ischemia and amputation, and diminish long-term survival prospects [12–14].

Given these challenges, it is crucial to accurately identify the risk factors associated with the failure to recover lower limb perfusion postoperatively in ATAAD patients. Early recognition of these factors could facilitate targeted interventions to improve surgical outcomes and mitigate postoperative complications. Previous studies have suggested several potential predictors of poor limb recovery, including the severity of preoperative limb ischemia, the duration of cardiopulmonary bypass, and intraoperative management strategies [14]. However, comprehensive analyses are warranted to comprehensively grasp the clinical attributes and risk factors contributing to unsuccessful postoperative recovery of limb function in these patients.

Therefore, this retrospective study aims to analyze the preoperative characteristics of 131 ATAAD patients complicated by LLM, with the goal of identifying clinical features and risk factors associated with postoperative failure to restore adequate limb perfusion. By elucidating these factors, the study endeavors to furnish valuable insights for refining preoperative evaluation, optimizing surgical strategies, and enhancing postoperative recovery of lower limb perfusion in this high-risk patient population. The study's outcomes may offer critical guidance for healthcare professionals in enhancing preoperative assessment and therapeutic strategies for ATAAD patients with lower extremity malperfusion, ultimately enhancing their prognosis.

Methods

Study Design and Participants

This retrospective study included 131 patients diagnosed with ATAAD complicated by LLM, who were admitted to a tertiary hospital in Nanjing from January 2013 to June 2019. The inclusion criteria comprised: (1) confirmation of Stanford type A aortic dissection through medical history, physical examination, echocardiography, and computed tomography angiography, followed by surgical intervention; (2) symptom onset within 14 days; and (3) preoperative diagnosis of LLM. The diagnosis of LLM was established based on classical clinical presentations such as absent femoral pulses, sensory or motor deficits in the extremity, skin pallor or cyanosis, and imaging evidence from computed tomography (CT) or ultrasound indicating diminished blood flow in the lower limb arteries [15]. Exclusion criteria were: (1) subacute or chronic ATAAD with symptom onset exceeding two weeks; (2) patients with other aortic pathologies, such as intramural hematoma or penetrating aortic ulcer, confirmed intraoperatively; (3) cases of iatrogenic aortic dissection; (4) lower extremity ischemia unrelated to aortic dissection, such as that caused by cerebral hemorrhage, cerebral infarction, or diabetic gangrene; and (5) patients with cerebral malperfusion (manifesting as consciousness disorders, strokes, or transient ischemic attacks).

Surgical Procedures

All patients underwent thorough preoperative management, which involved prompt admission to the intensive care unit (ICU). Continuous monitoring of arterial blood pressure was commenced, and mechanical ventilation via tracheal intubation was performed. Continuous intravenous infusion of muscle relaxants, analgesics, and sedatives was administered to maintain stable blood pressure and heart rate, thereby reducing the risk of aortic rupture.

After diagnosis, patients were promptly transferred to the cardiothoracic ICU, and all underwent central aortic repair surgery within 24 hours of symptom onset. The surgical procedure involved a standard median sternotomy. Following systemic heparinization, cardiopulmonary bypass (CPB) was established through femoral artery and/or right subclavian artery and right atrial cannulation. Upon reaching a nasopharyngeal temperature of 18–22 °C, CPB was temporarily ceased, and selective cerebral perfusion was initiated. After completing distal arch repair, CPB was resumed, and the patient was rewarmed [16]. All patients underwent one of four surgical techniques based on their condition. Total Arch and Descending Aortic Stent Implantation refers to a novel intraoperative hybrid stent graft system designed for open implantation, where the stent graft features a fenestrated design in the arch portion to ensure that it does not obstruct the three branch vessels [17]. Frozen Elephant Trunk Procedure (Sun's Procedure) involves total arch replacement combined with descending aortic stent implantation, in which the ascending aorta and the arch are replaced using a thoracic vascular graft, while the descending aorta is reconstructed with a Microport® stent-graft. Partial Arch Replacement is a procedure that replaces the ascending aorta and the lesser curvature of the aortic arch without involving direct manipulation of the branch vessels. Lastly, Island Anastomosis entails suturing the region containing the branch vessels to the synthetic vascular graft.

Data Collection

Data collection was conducted in two phases by clinical postgraduate students who had received appropriate training. In the first phase, general characteristics and admission-related symptoms and signs were documented within 48 hours of admission. In the second phase, intraoperative and postoperative data related to lower extremity ischemia recovery were collected at discharge.

General characteristics and admission-related symptoms included: sex, age, body mass index (BMI), unilateral or bilateral limb ischemia, lower extremity pain, skin pallor or mottling, absence of femoral and dorsalis pedis pulses, femoral pulse strength, muscle strength, skin temperature, blood pressure, and presence of diabetes mellitus or hypertension. Intraoperative and postoperative data comprised: surgical procedure, cardiopulmonary bypass time, aortic cross-clamp time, operation time, circulatory arrest time, and utilization of continuous renal replacement therapy (CRRT).

The primary endpoint was the postoperative recovery of limb function, which was defined as the restoration of normal muscle strength and the absence of symptoms such as neuralgia or motor dysfunction at the time of discharge. Resolution of lower extremity malperfusion was determined by meeting these criteria. Conversely, patients who succumbed to their condition or had persistent malperfusion were classified as having unrecovered lower extremity function.

Statistical Analysis

Patients were divided into two groups according to the resolution status of postoperative lower limb ischemia. A comparative analysis of general characteristics, symptoms, and signs at admission was conducted between the recovery and non-recovery groups.

Continuous variables were summarized as medians and interquartile ranges (IQR) and compared using Student's *t*-test or the Mann-Whitney U-test, as appropriate. Categorical variables were presented as frequencies or percentages and analyzed using the Chi-squared test or Fisher's exact test. Variables with a p value < 0.1 in the univariate analysis were further assessed using multivariate logistic regression models to identify independent predictors. The selection of variables for multivariate analysis was guided by their clinical relevance and statistical significance in the univariate analysis. A backward stepwise approach was applied to exclude non-significant variables from the final model. To address potential confounding factors, all clinically relevant covariates, including age, sex, comorbidities (e.g., diabetes, hypertension), and perioperative factors, were adjusted for in the multivariate model. Results were reported as odds ratios (OR) with 95% confidence intervals (CI). A two-sided p value <0.05 was considered statistically significant. For variables with missing data, multiple imputation was performed to minimize potential bias. Statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA) or R software (version 4.2.0, R Foundation for Statistical Computing, Vienna, Austria).

Results

Baseline Characteristics

Among 1092 patients with acute type A aortic dissection, 133 (12.18%) had preoperative LEM, with a mortality rate of 22.56%, compared to 13.35% in patients without LEM. The overall mortality rate for the cohort was 14.47% (158/1092). Univariate analysis showed that preoperative LEM was associated with a significantly higher risk of mortality (OR = 2.123, $p < 0.001$). Flowchart of participant selection is shown in Fig. 1.

Following the application of the exclusion criteria, a total of 131 patients were included in the study. These patients were divided into two groups based on the postoperative recovery of lower limb perfusion. Within the cohort, 80 patients (62.5%) experienced recovery of lower limb perfusion, while 51 patients (37.5%) did not recover from postoperative lower limb perfusion impairment.

The ages of the study participants ranged from 28 to 82 years, with a mean age of 52.44 $\pm$ 12.92 years. The average BMI was 25.87 $\pm$ 4.26 kg/m^2. The cohort included 102

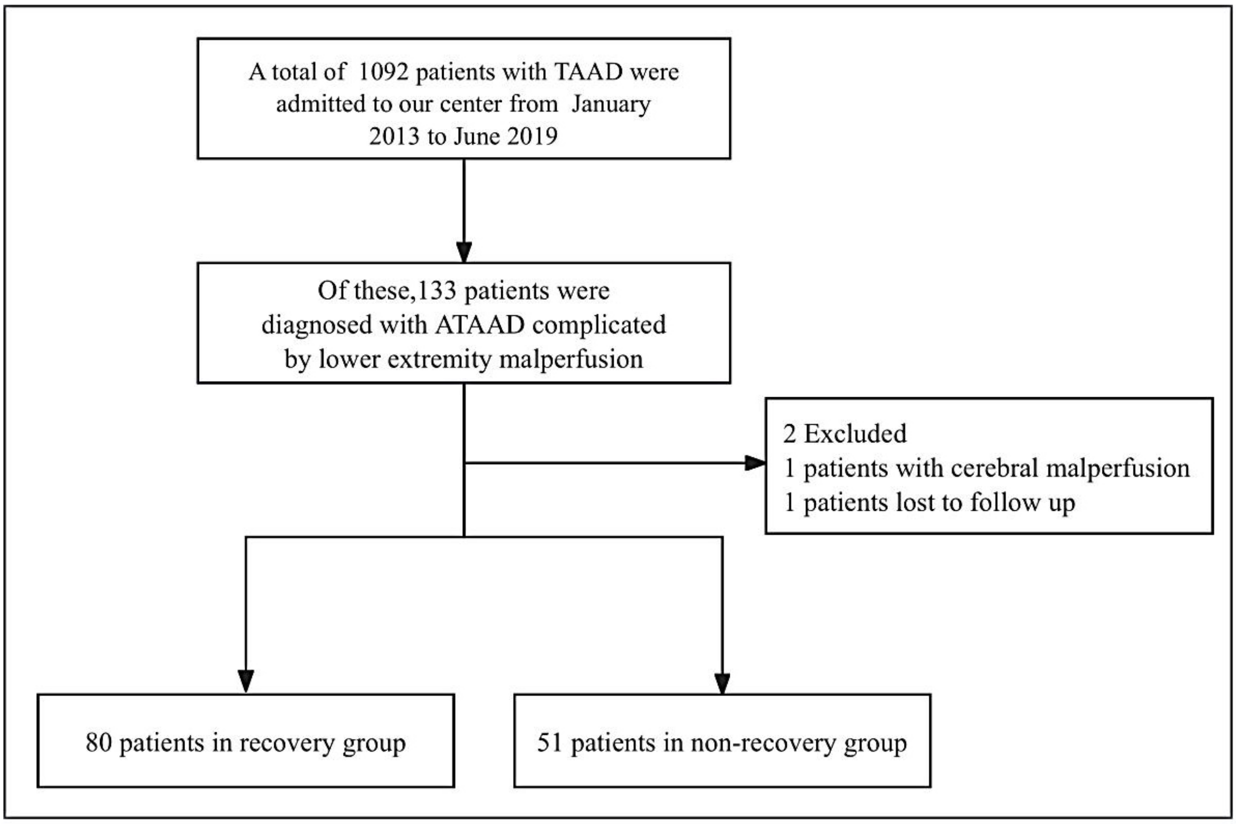

Fig. 1. Flowchart of participant selection. ATAAD, acute type A aortic dissection; TAAD, type A aortic dissection.

male patients (77.9%) and 29 female patients (22.1%). A history of hypertension was present in 103 patients (78.6%), and 4 patients (3.1%) had a history of diabetes mellitus. Detailed baseline characteristics are presented in Table 1.

Univariate Analysis of Factors Influencing Limb Function Recovery in Acute Type A Aortic Dissection

Univariate analysis was performed on all patient data to identify potential factors influencing limb function recovery. The results revealed statistically significant differences for eight variables: ischemic symptoms (OR = 3.84, $p < 0.01$), paresthesia (OR = 2.197, $p = 0.031$), decreased muscle strength (OR = 2.594, $p = 0.016$), reduced skin temperature (OR = 2.475, $p = 0.014$), non-measurable blood pressure (OR = 2.667, $p = 0.010$), cardiopulmonary bypass time (OR = 1.008, $p = 0.002$), aortic cross-clamp time (OR = 1.008, $p = 0.018$), and the utilization of CRRT (OR = 8.095, $p < 0.01$). These variables demonstrated statistically significant associations with limb function recovery, as detailed in Table 2.

Multivariable Analysis of Factors Influencing Limb Function Recovery in Acute Type A Aortic Dissection

Multivariable logistic regression analysis revealed that ischemic symptoms (OR = 4.519, $p = 0.001$), non-measurable blood pressure (OR = 2.720, $p = 0.033$), and prolonged cardiopulmonary bypass time (OR = 1.018, $p = 0.011$) were identified as independent risk factors for the lack of postoperative ischemia recovery in patients with Stanford type A aortic dissection complicated by lower limb ischemia. These findings suggest that the presence of ischemic symptoms, non-measurable blood pressure, and longer cardiopulmonary bypass time serve as significant predictors of inadequate limb function recovery following surgery (Table 3).

The performance of the regression model was evaluated using a receiver operating characteristic (ROC) curve, which demonstrated an area under the curve (AUC) of 0.769, indicating a moderate predictive ability (Fig. 2).

Discussion

LEM represents a severe and life-threatening complication in patients with ATAAD, contributing to elevated mortality and worse clinical outcomes. In our study, LEM was identified in 12.18% of ATAAD patients, with a strikingly higher mortality rate of 22.56%, compared to 13.35% in those without LEM. Univariate analysis further established LEM as an independent risk factor for increased mortality (OR = 2.123, $p < 0.001$), underscoring its critical impact on patient prognosis. These findings align with prior research, which has demonstrated that LEM is associated

Table 1. Baseline characteristics in patients with type A aortic dissection and preoperative lower extremity malperfusion based on recovery of lower extremity malperfusion after surgery [n (%), ($\bar{x} \pm s$), median].

		All (n = 131)	Recovery group (n = 80)	Non-recovery group (n = 51)	*p*
Female, n (%)		29 (22.1)	18 (22.5)	11 (21.6)	0.999
Age, (years) mean (SD)		52.44 (12.92)	52.04 (12.53)	53.08 (13.62)	0.655
BMI, (kg/m^2) mean (SD)		25.87 (4.26)	25.43 (4.11)	26.57 (4.44)	0.134
Lower Limb Pain, n (%)		9 (6.9)	5 (6.2)	4 (7.8)	0.999
Paresthesia in Lower Limbs, n (%)		59 (45.0)	30 (37.5)	29 (56.9)	0.046
Pale or Mottled Skin, n (%)		4 (3.1)	1 (1.2)	3 (5.9)	0.326
Ischemic Symptoms, n (%)	single	77 (58.8)	57 (71.2)	20 (39.2)	0.001
	both	54 (41.2)	23 (28.7)	31 (60.8)	
Absence of Femoral and Dorsalis Pedis Artery Pulses, n (%)	Femoral artery	3 (2.3)	2 (2.5)	1 (2.0)	0.017
	Dorsalis pedis artery	46 (35.1)	31 (38.8)	15 (29.4)	
	both	34 (26.0)	13 (16.2)	21 (41.2)	
Femoral Artery Pulse Strength, n (%)	none	83 (63.4)	56 (70.0)	27 (52.9)	0.024
	weaken	9 (6.9)	7 (8.8)	2 (3.9)	
	normal	39 (29.8)	17 (21.2)	22 (43.1)	
Dorsalis Pedis Artery Pulse Strength, n (%)	none	13 (9.9)	9 (11.2)	4 (7.8)	0.202
	weaken	38 (29.0)	27 (33.8)	11 (21.6)	
	normal	80 (61.1)	44 (55.0)	36 (70.6)	
Decreased Muscle Strength, n (%)		38 (29.0)	17 (21.2)	21 (41.2)	0.024
Reduced Skin Temperature, n (%)		52 (39.7)	25 (31.2)	27 (52.9)	0.022
Non-Measurable Blood Pressure, n (%)		44 (33.6)	20 (25.0)	24 (47.1)	0.016
Diabetes Mellitus, n (%)		4 (3.1)	3 (3.8)	1 (2.0)	0.952
Hypertension, n (%)		103 (78.6)	62 (77.5)	41 (80.4)	0.861
Continuous Renal Replacement Therapy, n (%)		39 (29.77)	12 (15.00)	27 (52.94)	<0.001
Surgical Procedure, n (%)	Total Arch and Descending Aortic Stent Implantation	52 (39.7)	35 (43.8)	17 (33.3)	0.641
	Frozen Elephant Trunk Procedure (Sun's Procedure)	52 (39.7)	29 (36.3)	23 (45.1)	
	Partial Arch Replacement	21 (16.0)	12 (15.0)	9 (17.6)	
	Island Anastomosis	6 (4.6)	4 (5.0)	2 (3.9)	
Cardiopulmonary Bypass Time, (min) median [IQR]		231.00 [193.50, 269.00]	218.00 [180.00, 255.25]	253.00 [215.50, 329.00]	0.001
Aortic Cross-Clamp Time, (min) median [IQR]		160.00 [127.50, 206.00]	149.50 [123.75, 187.00]	175.00 [149.00, 225.00]	0.011
Operation Time, (hours) median [IQR]		7.83 [6.50, 9.67]	7.33 [6.17, 8.50]	9.00 [7.50, 10.33]	<0.001
Circulatory Arrest Time, (min) median [IQR]		31.00 [24.00, 38.00]	30.00 [24.00, 38.00]	31.00 [23.50, 38.00]	0.962

SD, standard deviation; IQR, interquartile ranges; BMI, body mass Index.

Table 2. Univariate analysis of influencing factors for limb function recovery in acute type A aortic dissection.

	Variables	OR	2.50%	97.50%	B	Wald	*p* value
1	Ischemic Symptoms	3.841	1.850	8.197	1.346	12.641	<0.001
2	Paresthesia	2.197	1.080	4.538	0.787	4.648	0.031
3	Decreased Muscle Strength	2.594	1.203	5.688	0.953	5.838	0.016
4	Reduced Skin Temperature	2.475	1.205	5.162	0.906	6.000	0.014
5	Non-Measurable Blood Pressure	2.667	1.270	5.692	0.981	6.618	0.010
6	Cardiopulmonary Bypass Time	1.008	1.003	1.014	0.008	9.910	0.002
7	Aortic Cross-Clamp Time	1.008	1.001	1.014	0.007	5.579	0.018
8	Continuous Renal Replacement Therapy	8.095	3.620	19.165	2.091	24.434	<0.001

OR, odds ratio.

Table 3. Multivariable analysis of influencing factors for limb function recovery in acute type A aortic dissection.

	Variables	OR	2.50%	97.50%	B	Wald	*p*
1	Ischemic Symptoms	4.519	1.910	11.320	1.508	11.192	0.001
2	Non-Measurable Blood Pressure	2.720	1.093	6.996	1.001	4.526	0.033
3	Cardiopulmonary Bypass Time	1.018	1.006	1.034	0.018	6.529	0.011

with more extensive aortic dissections and the involvement of other vital organ systems, such as the renal and mesenteric vasculature, thereby amplifying the severity of MPS and worsening clinical outcomes [18,19]. The mechanisms by which LEM contributes to increased mortality are multifaceted. This perfusion deficit sets off a cascade of pathological processes, including ischemia-reperfusion injury, systemic inflammatory response syndrome, and progression to multiple organ dysfunction syndrome, all of which exacerbate clinical deterioration [20].

The clinical significance of LEM is further emphasized by the fact that 20% to 40% of ATAAD patients present with varying degrees of malperfusion at admission, and 9.7% to 15% suffer from LLM [21]. The presence of LLM often indicates a more extensive aortic dissection, frequently accompanied by malperfusion of other major branches, such as the celiac trunk and renal arteries, thereby complicating the clinical scenario significantly. In ATAAD, the primary mechanism of LLM involves increased pressure within the false lumen, leading to compression of the true lumen and subsequent reduction or complete obstruction of blood flow. Additionally, the acute nature of the occlusion prevents the establishment of effective collateral circulation, leading to limb ischemia. Previous studies have shown that the severity of limb ischemia is influenced by the degree of obstruction, the duration of ischemia, and the presence or absence of collateral circulation. Skeletal muscle necrosis can commence as early as three hours following complete ischemia, with irreversible necrosis occurring after six hours [22]. Despite significant advances in the surgical treatment of ATAAD, leading to reductions in operative mortality and complications, the restoration of postoperative lower limb perfusion in patients with preoperative LLM remains a challenge. Our study identified that bilateral ischemic symptoms, non-measurable blood pressure, and prolonged CPB time are independent risk factors associated with the inability to achieve postoperative limb perfusion recovery.

This study found that bilateral lower limb ischemic symptoms are an independent risk factor for inadequate postoperative limb perfusion recovery. Patients with bilateral limb ischemic symptoms had a 4.519-fold higher risk of persistent postoperative limb malperfusion compared to those with unilateral symptoms. This may be attributed to the presence of complete or near-complete occlusion of the true lumen in the thoracoabdominal aorta (true lumen area <30%) among patients with bilateral limb ischemia, resulting in compromised antegrade perfusion to the lower extremities. Consequently, these patients face a greater susceptibility to intraoperative and postoperative limb malperfusion [23]. Clinically, when encountering ATAAD patients with bilateral lower limb ischemia, clinicians should remain vigilant, continuously assess the ischemic status, and expedite efforts to restore limb perfusion to prevent irreversible damage.

Our results also indicated that preoperative non-measurable blood pressure is an independent risk factor for poor postoperative limb perfusion recovery. Patients with non-measurable blood pressure exhibited a 2.720-fold higher risk of persistent postoperative limb malperfusion compared to those with measurable blood pressure. Studies have reported that hypotension in patients with acute aortic dissection is frequently associated with pericardial tamponade or rupture of the aortic dissection due to external leakage of blood from the ascending aorta, severe aortic valve insufficiency or coronary artery obstruction leading to acute heart failure. These patients typically have a poor prognosis [24]. Additionally, given that the lower limbs receive blood supply from the most distal branches of the aorta, significant engagement of these vessels suggests a more widespread dissection. In such cases, non-measurable blood pressure may result from arterial occlusion, a condi-

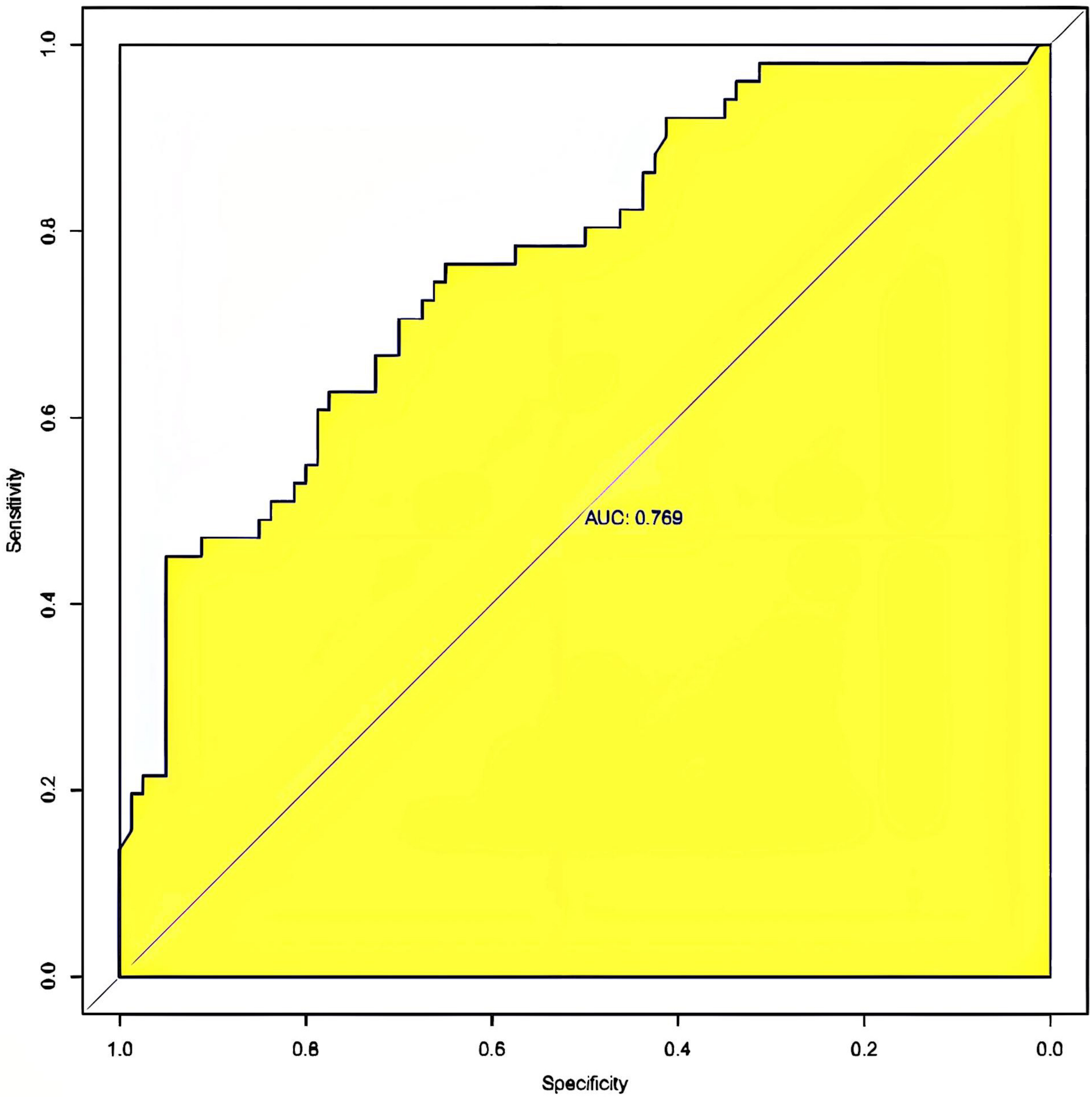

Fig. 2. The receiver operating curve of logistic model. AUC, area under curve.

tion frequently associated with more severe ischemia than in patients with measurable blood pressure, thereby increasing the likelihood of poor postoperative recovery.

Furthermore, prolonged CPB time emerged as a factor associated with inadequate postoperative limb perfusion recovery. Prolonged CPB could exacerbate lower limb ischemic injury due to extended cardiac arrest and reperfusion. The severity of limb ischemia depends on both the degree and duration of obstruction, underscoring the critical importance of minimizing ischemic duration. Intraoperative collaboration among multidisciplinary teams, particularly the CPB team, is essential for the timely restoration of limb perfusion. The complexity and duration of aortic dissection surgery often present challenges in achieving timely reperfusion within the optimal ischemic timeframe, further aggravating tissue damage in the affected limbs. Additionally, prolonged CPB time often signifies more severe disease or intricate surgical interventions. LLM is frequently accompanied by visceral or renal malperfusion, worsening perfusion pressure in the distal vasculature and increasing the likelihood of intraoperative vascular grafting procedures, which, in turn, prolong CPB duration. Previous studies have also shown that prolonged CPB time is a risk factor for mortality in patients with preoperative MPS [25]. In this study, patients who died were considered to have unresolved limb malperfusion. Therefore, the reduction of CPB duration and minimization of surgical trauma are paramount in enhancing postoperative recovery of lower limb perfusion and reducing associated complications.

Limitations

Several limitations of this study warrant acknowledgment. Firstly, its retrospective design could potentially introduce selection bias, given that data were obtained from medical records rather than through prospective means. Secondly, the relatively small sample size, particularly in the non-recovery group, may restrict the statistical power and the generalizability of our findings to larger populations. Thirdly, the single-center nature of this study may diminish the external validity of the findings when applied to more diverse and heterogeneous populations. Additionally, while we identified several early predictors of poor postoperative LEM recovery, certain potential factors, including specific intraoperative techniques, postoperative management strategies, and patient comorbidities, were not fully explored. Furthermore, the lack of long-term follow-up data on limb function recovery limited our ability to assess the sustained outcomes and potential late complications beyond the immediate postoperative period.

Future multicenter, prospective studies with larger sample sizes, comprehensive data on intraoperative and postoperative factors, and longer follow-up periods are needed to validate these findings, improve statistical robustness, and explore additional predictors and interventions aimed at optimizing clinical outcomes.

Conclusion

In the treatment of Stanford type A aortic dissection complicated by lower extremity malperfusion, the primary objective is not only to save the patient's life but also to enhance postoperative quality of life, with a specific focus on preserving limb function. This study identified early predictors of limb function recovery in patients with acute Stanford type A aortic dissection and lower limb ischemia based on admission data. The key predictors include bilateral limb ischemia, non-measurable blood pressure, and prolonged CPB time. However, this study has certain limitations, primarily due to the relatively small sample size, which may introduce bias. Additionally, the uncertainty regarding whether additional symptoms from the "6P" signs of ischemia can function as early predictors poses a noteworthy limitation. Future studies involving larger, multicenter cohorts are imperative to corroborate and expand upon these findings, as well as to explore other potential predictive factors.

Availability of Data and Materials

Availability of data and materials can be provided by authors if it is on valid basis.

Author Contributions

PZ, JJB, MYW, YXH, HTZ, QZ, XLX, and YYS contributed to the conception and design of the study. PZ, JJB, MYW, YXH, HTZ, and QZ were involved in the acquisition, analysis, and interpretation of data. XLX and YYS designed the study and wrote the manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics Approval and Consent to Participate

The study was carried out in accordance with the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of Nanjing Drum Tower Hospital (2020-281-01). The requirement for informed consent was waived due to the anonymized nature of the data.

Acknowledgment

Not applicable.

Funding

This study was supported by the Medical Key Science and Technology Development Project of Nanjing Health Science and Technology Development Special Fund Project (ZKX23024); Clinical Research Special Fund of Nanjing Gulou Hospital (2023-LCYJ-PY–22).

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Okita Y, Miyata H, Motomura N, Takamoto S, Japan Cardiovascular Surgery Database Organization. A study of brain protection during total arch replacement comparing antegrade cerebral perfusion versus hypothermic circulatory arrest, with or without retrograde cerebral perfusion: analysis based on the Japan Adult Cardiovascular Surgery Database. The Journal of Thoracic and Cardiovascular Surgery. 2015; 149: S65–S73. https://doi.org/10.1016/j.jtcvs.2014.08.070.

[2] Tolenaar JL, Froehlich W, Jonker FHW, Upchurch GR, Jr, Rampoldi V, Tsai TT, *et al*. Predicting in-hospital mortality in acute type B aortic dissection: evidence from International Registry

of Acute Aortic Dissection. Circulation. 2014; 130: S45–S50. https://doi.org/10.1161/CIRCULATIONAHA.113.007117.

[3] Bossone E, LaBounty TM, Eagle KA. Acute aortic syndromes: diagnosis and management, an update. European Heart Journal. 2018; 39: 739d–749d. https://doi.org/10.1093/eurheartj/ehx319.

[4] Malaisrie SC, Szeto WY, Halas M, Girardi LN, Coselli JS, Sundt TM, 3rd, *et al*. 2021 The American Association for Thoracic Surgery expert consensus document: Surgical treatment of acute type A aortic dissection. The Journal of Thoracic and Cardiovascular Surgery. 2021; 162: 735–758.e2. https://doi.org/10.1016/j.jtcvs.2021.04.053.

[5] Isselbacher EM, Preventza O, Hamilton Black J, 3rd, Augoustides JG, Beck AW, Bolen MA, *et al*. 2022 ACC/AHA Guideline for the Diagnosis and Management of Aortic Disease: A Report of the American Heart Association/American College of Cardiology Joint Committee on Clinical Practice Guidelines. Circulation. 2022; 146: e334–e482. https://doi.org/10.1161/CIR.0000000000001106.

[6] Zindovic I, Gudbjartsson T, Ahlsson A, Fuglsang S, Gunn J, Hansson EC, *et al*. Malperfusion in acute type A aortic dissection: An update from the Nordic Consortium for Acute Type A Aortic Dissection. The Journal of Thoracic and Cardiovascular Surgery. 2019; 157: 1324–1333.e6. https://doi.org/10.1016/j.jtcvs.2018.10.134.

[7] Narayan P, Rogers CA, Benedetto U, Caputo M, Angelini GD, Bryan AJ. Malperfusion rather than merely timing of operative repair determines early and late outcome in type A aortic dissection. The Journal of Thoracic and Cardiovascular Surgery. 2017; 154: 81–86. https://doi.org/10.1016/j.jtcvs.2017.03.041.

[8] Kawahito K, Kimura N, Yamaguchi A, Aizawa K. Malperfusion in type A aortic dissection: results of emergency central aortic repair. General Thoracic and Cardiovascular Surgery. 2019; 67: 594–601. https://doi.org/10.1007/s11748-019-01072-z.

[9] Berretta P, Trimarchi S, Patel HJ, Gleason TG, Eagle KA, Di Eusanio M. Malperfusion syndromes in type A aortic dissection: what we have learned from IRAD. Journal of Visualized Surgery. 2018; 4: 65. https://doi.org/10.21037/jovs.2018.03.13.

[10] Beck CJ, Germano E, Artis AS, Kirksey L, Smolock CJ, Lyden SP, *et al*. Outcomes and role of peripheral revascularization in type A aortic dissection presenting with acute lower extremity ischemia. Journal of Vascular Surgery. 2022; 75: 495–503.e5. https://doi.org/10.1016/j.jvs.2021.08.050.

[11] Fujita W, Daitoku K, Taniguchi S, Fukuda I. Endovascular stent placement for acute type-B aortic dissection with malperfusion–an intentional surgical delay and a possible 'bridging therapy'. Interactive Cardiovascular and Thoracic Surgery. 2009; 8: 266–268. https://doi.org/10.1510/icvts.2008.191361.

[12] Di Eusanio M, Trimarchi S, Patel HJ, Hutchison S, Suzuki T, Peterson MD, *et al*. Clinical presentation, management, and short-term outcome of patients with type A acute dissection complicated by mesenteric malperfusion: observations from the International Registry of Acute Aortic Dissection. The Journal of Thoracic and Cardiovascular Surgery. 2013; 145: 385–390.e1. https://doi.org/10.1016/j.jtcvs.2012.01.042.

[13] Kamman AV, Yang B, Kim KM, Williams DM, Michael Deeb G, Patel HJ. Visceral Malperfusion in Aortic Dissection: The Michigan Experience. Seminars in Thoracic and Cardiovascular Surgery. 2017; 29: 173–178. https://doi.org/10.1053/j.semtcvs.2016.10.002.

[14] Howe KL, Harlock J, Parry D. Management of Lower Extremity Ischaemia During Type A Dissection Repair. EJVES Short Reports. 2018; 39: 44–46. https://doi.org/10.1016/j.ejvssr.2018.05.011.

[15] White RA, Miller DC, Criado FJ, Dake MD, Diethrich EB, Greenberg RK, *et al*. Report on the results of thoracic endovascular aortic repair for acute, complicated, type B aortic dissection at 30 days and 1 year from a multidisciplinary subcommittee of the Society for Vascular Surgery Outcomes Committee. Journal of Vascular Surgery. 2011; 53: 1082–1090. https://doi.org/10.1016/j.jvs.2010.11.124.

[16] Xue Y, Zhou Q, Pan J, Cao H, Fan F, Zhu X, *et al*. "Double Jacket Wrapping" Root Reconstruction for Acute Type A Aortic Dissection. The Annals of Thoracic Surgery. 2020; 110: 1060–1062. https://doi.org/10.1016/j.athoracsur.2020.03.081.

[17] Zhou Q, Xue Y, Cao H, Pan J, Wang Q, Fan F, *et al*. Novel arch fenestrated stent graft for acute Stanford Type A aortic dissection with open antegrade implantation. Interactive Cardiovascular and Thoracic Surgery. 2018; 26: 369–375. https://doi.org/10.1093/icvts/ivx335.

[18] Zhou Y, Fan R, Jiang H, Liu R, Huang F, Chen X. A novel nomogram model to predict in-hospital mortality in patients with acute type A aortic dissection after surgery. Journal of Cardiothoracic Surgery. 2024; 19: 362. https://doi.org/10.1186/s13019-024-02921-6.

[19] Yuan H, Sun Z, Zhang Y, Wu W, Liu M, Yang Y, *et al*. Clinical Analysis of Risk Factors for Mortality in Type A Acute Aortic Dissection: A Single Study From China. Frontiers in Cardiovascular Medicine. 2021; 8: 728568. https://doi.org/10.3389/fcvm.2021.728568.

[20] Charlton-Ouw KM, Sandhu HK, Leake SS, Jeffress K, Miller CC, Rd, Durham CA, *et al*. Need for Limb Revascularization in Patients with Acute Aortic Dissection is Associated with Mesenteric Ischemia. Annals of Vascular Surgery. 2016; 36: 112–120. https://doi.org/10.1016/j.avsg.2016.03.012.

[21] Yang B, Rosati CM, Norton EL, Kim KM, Khaja MS, Dasika N, *et al*. Endovascular Fenestration/Stenting First Followed by Delayed Open Aortic Repair for Acute Type A Aortic Dissection With Malperfusion Syndrome. Circulation. 2018; 138: 2091–2103. https://doi.org/10.1161/CIRCULATIONAHA.118.036328.

[22] Blaisdell FW. The pathophysiology of skeletal muscle ischemia and the reperfusion syndrome: a review. Cardiovascular Surgery (London, England). 2002; 10: 620–630. https://doi.org/10.1016/s0967-2109(02)00070-4.

[23] Yassin MMI, Harkin DW, Barros D'Sa AAB, Halliday MI, Rowlands BJ. Lower limb ischemia-reperfusion injury triggers a systemic inflammatory response and multiple organ dysfunction. World Journal of Surgery. 2002; 26: 115–121. https://doi.org/10.1007/s00268-001-0169-2.

[24] Gargotta HR. Type A Aortic Dissection Complicated by Renal and Lower Extremity Malperfusion. Advanced Emergency Nursing Journal. 2019; 41: 23–32. https://doi.org/10.1097/TME.0000000000000220.

[25] Okita Y, Okada K. Treatment strategies for malperfusion syndrome secondary to acute aortic dissection. Journal of Cardiac Surgery. 2021; 36: 1745–1752. https://doi.org/10.1111/jocs.14983.