Lower-extremity malperfusion syndrome in patients undergoing proximal aortic surgery for acute type A aortic dissection

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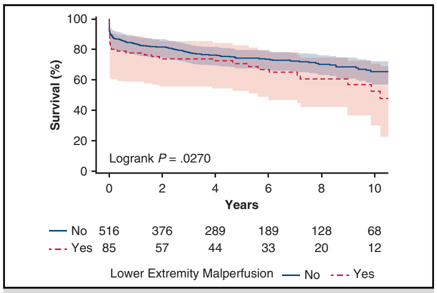
ABSTRACT

Objective: Data regarding management of lower-extremity malperfusion in the setting of type A aortic dissection are limited. This study aimed to compare acute type A aortic dissection with lower-extremity malperfusion outcomes in patients undergoing lower-extremity revascularization with no revascularization.

Methods: Consecutive patients undergoing acute type A aortic dissection surgery were identified from a prospectively maintained database. Perioperative variables were compared between patients with and without lower-extremity malperfusion. Factors associated with lower-extremity malperfusion, revascularization, and mortality were determined using univariable Cox regression and Firth's penalized likelihood modeling.

Results: From January 2007 to December 2021, 601 patients underwent proximal aortic repair for acute type A aortic dissection at a quaternary care center. Of these, 85 of 601 patients (14%) presented with lower-extremity malperfusion and were more often male ($P = .02$), had concomitant moderate or greater aortic insufficiency ($P = .05$), had lower ejection fraction ($P = .004$), had preoperative dialysis dependence ($P = .01$), and had additional cerebral, visceral, and renal malperfusion syndromes ($P < .001$). Kaplan–Meier estimated survival fared worse with lower-extremity malperfusion compared with no lower-extremity malperfusion at 1, 5, and 10 years (84% vs 77%, 74% vs 71%, 65% vs 52%, respectively, $P = .03$). In the lower-extremity malperfusion group, 15 of 85 patients (18%) underwent lower-extremity revascularization without significant differences in postoperative morbidity and mortality compared with patients not undergoing revascularization. Need for peripheral revascularization was associated with peripheral vascular disease (hazard ratio, 3.7 [1.0-14.0], $P = .05$) and pulse deficit (hazard ratio, 5.6 [1.3-24.0], $P = .02$) at presentation.

Conclusions: Patients presenting with type A aortic dissection and lower-extremity malperfusion have worse overall survival compared with those without lower-extremity malperfusion. However, not all patients with type A aortic dissection and lower-extremity malperfusion require revascularization. (JTCVS Open 2023;15:1-13)



Survival in TAAD with and without lower-extremity malperfusion.

CENTRAL MESSAGE

With careful selection, LEM often resolves after proximal repair of TAAD.

PERSPECTIVE

Presentation of LEM in TAAD increases mortality, but optimal management in this complex situation is not well established. We found LEM resolved for a majority of patients after proximal aortic repair and identified factors associated with the need for revascularization.

See Discussion on page 14.

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Abbreviations and Acronyms

CI	= confidence interval
CT	= computed tomography
HR	= hazard ratio
LEM	= lower-extremity malperfusion
OR	= odds ratio
PVD	= peripheral vascular disease
TAAD	= type A aortic dissection

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Acute aortic dissection management and outcomes are significantly influenced by the extent and location of dissection. Acute type A aortic dissection (TAAD) is typically managed with emergency surgery with mortality outcomes ranging from 15% to 30%.[1,2] Perioperative outcomes for TAAD are particularly worse in the setting of malperfusion syndromes, with mortality rates increasing up to 43%.[3-5] Concomitant lower-extremity malperfusion (LEM) occurs in less than 20% to 30% of patients presenting with TAAD, but the presence of preoperative limb ischemia increases the risk of mortality up to 2-fold.[1,5-7] Although LEM has been identified as an important determinant of mortality in TAAD repair, there are few data comparing outcomes and optimal management in this complex situation.

The purpose of this study was to identify key differences in baseline characteristics and perioperative outcomes for patients undergoing TAAD repair with and without concomitant LEM. The LEM group was further analyzed to identify variables associated with lower-extremity revascularization and mortality.

MATERIALS AND METHODS

Study Design

The Institutional Review Board or equivalent ethics committee of the University of Pittsburgh Medical Center approved the study protocol and publication of data on January 30, 2018 (Institutional Review Board #18120143). The patients provided informed written consent for the publication of the study data. Consecutive patients who underwent proximal aortic repair for TAAD were extracted from a prospectively maintained database between January 2007 and December 2021. Adult patients (age >18 years) with type A dissections presenting within 14 days of symptoms and undergoing open repair were included. Type B aortic dissections were excluded. Traumatic or iatrogenic aortic and peripheral vascular injuries were excluded.

Data Collection

Baseline health characteristics, intraoperative details, and in-hospital postoperative outcomes were obtained from an institutional database. LEM was defined by clinical symptoms with or without radiologic findings. Clinical symptoms included lower-extremity pain, paralysis, loss of sensation, pallor, paresthesias, and pulse deficit. Radiographic findings consistent with LEM included an aortic dissection extending to the common iliac or external iliac arteries. Patients with concomitant LEM and TAAD were identified, and additional data for these patients were collected through electronic medical records. Preoperative computed tomography (CT) imaging was reviewed to determine aortic dissection and LEM characteristics. Patients undergoing limb-related revascularization were then identified for subanalysis. End points of reintervention, amputation, and mortality were extracted through retrospective review of electronic records. Reintervention and amputation outcomes were specifically reviewed up to 1 year after the index operation. Follow-up data were obtained from the clinical warehouse that contains all long-term survival data for patients undergoing cardiac and aortic surgery at the University of Pittsburgh Medical Center. If patients were noted to be deceased but with no confirmed date, they were excluded from mortality analysis (unknown death date, n = 1). For patients who did not develop the event of interest (death) before September 15, 2021, when the information was extracted, the last date we have their information for serves as the censoring date.

Operative Details

A central aortic repair first strategy was applied for all patients except in cases of a threatened limb where revascularization was performed concomitantly with the index proximal aortic repair. Patients who underwent lower-extremity revascularization presented most frequently with absent pulses or clinical symptoms of LEM such as pain, decreased lower-extremity sensation, and paresthesias with correlating radiologic findings of lumen narrowing or dissection extending to the common or external iliac artery. The sequence of concomitant treatment was determined by urgency and surgeon preference, with lower-extremity revascularization performed before central aortic repair in 8 patients and after central aortic repair in 7 patients. There were 2 endovascular stents and 13 open interventions that were femoral-femoral arterial crossover bypass grafts. All lower-extremity interventions were performed by the cardiac surgery team.

Data Analysis

Baseline characteristics are presented as frequency (percentage) for categorical variables and mean (standard deviation) or median (interquartile range) for continuous variables that are or are not normally distributed, respectively. The distribution of data was examined by Shapiro-Wilk test. For categorical variables, Pearson's chi-square test was used for categorical comparisons. For continuous variables, Student *t* test or Mann–Whitney *U* test was used for comparison of the mean and median, respectively.

For logistic regression or multivariable Cox regression analysis, covariates other than lower extremity from the baseline characteristics (Table 1) were included in the model using the method of stepwise selection with a threshold of inclusion at P less than .2. The assumption of proportional hazards was validated using Schoenfeld residuals. In general, for variables that are included in the regression models, missing variables (usually <5%) were replaced by the mean value (for a continuous variable) or the most frequent categories (for a categorical variable).

Long-term survival curves were plotted using Kaplan–Meier estimate. Differences in the survival curves were analyzed using log-rank testing. Statistical analysis was performed using SAS version 9.4 (SAS Institute Inc).

Supplementary propensity score–matched analyses were performed using greedy nearest neighbor caliper matching, with calipers of width setting at 0.2 of standard deviation. Covariate balance is assessed by the P value and standardized mean difference with a threshold setting at 0.25. Propensity score matching incorporated preoperative variables provided in Table E1. All statistical analyses were performed using SAS/STAT Version 15.2 (SAS Institute Inc). All tests were 2-sided with an alpha level of 0.05 designated to indicate statistical significance.

TABLE 1. Comparison of preoperative variables between patients with type A aortic dissection with and without concurrent lower-extremity malperfusion

Preoperative baseline variables	No LEM (n = 516)	LEM (n = 85)	*P* value
Age (y)	61.7 ± 13.8	59.2 ± 11.1	.11
Female gender	216 (41.86)	24 (28.24)	.02
White	426 (82.56)	67 (78.82)	.41
Body mass index (kg/m^2)	30.0 ± 6.69	30.1 ± 6.72	.94
Hypertension	397 (76.94)	60 (70.59)	.20
Diabetes mellitus	56 (10.85)	7 (8.24)	.47
Chronic lung disease	78 (15.12)	8 (9.41)	.16
Peripheral vascular disease	174 (33.72)	33 (38.82)	.36
Atrial fibrillation	55 (10.66)	6 (7.06)	.31
Coronary artery disease	76 (14.73)	10 (11.76)	.47
Redo heart surgery	65 (12.60)	7 (8.24)	.25
Aortic insufficiency moderate or greater	208 (40.31)	44 (51.76)	.05
Ejection fraction	55.8 ± 8.78	52.6 ± 13.0	.004
Tamponade, rupture, or shock	158 (30.62)	29 (34.12)	.52
Dialysis dependent	8 (1.55)	5 (5.88)	.01
Hematocrit	38.3 ± 6.02	39.4 ± 6.56	.18
Creatinine level	1.28 ± 1.01	1.44 ± 1.09	.25
Type of malperfusion syndrome			
Cerebral	53 (10.27)	21 (24.71)	<.001
Coronary	37 (7.17)	5 (5.88)	.67
Visceral	20 (3.88)	15 (17.65)	<.001
Renal	14 (2.71)	22 (25.88)	<.001

LEM, Lower-extremity malperfusion.

RESULTS

There were 601 patients from January 2007 to December 2021 who underwent TAAD proximal aortic repair at a single tertiary care center; of these patients, 85 of 601 (14%) presented with concomitant LEM. All 15 patients undergoing revascularization had clinical evidence of malperfusion such as pain, decreased lower-extremity sensation, paresthesias, or pulse deficit with or without radiographic evidence. Radiographic evidence of malperfusion was present in 10 of 15 patients undergoing revascularization. Preoperative, intraoperative, and postoperative outcome comparisons between patients with and without LEM are presented in Tables 1 and 2. Propensity-matched comparison based on preoperative characteristics is described in Tables E1 and E2. Kaplan–Meier estimated overall survival fared worse in patients with LEM compared with patients without LEM at 1, 5, and 10 years (84% vs 77%, 74% vs 71%, 65% vs 52%, respectively, $P = .03$) (Figure 1). For the entire cohort, LEM was not independently associated with increased mortality at 1 year (hazard ratio [HR], 1.42, confidence interval [CI], 0.84-2.40, $P = .19$) (Table E3).

Within the LEM group, 18% of patients (15/85) underwent lower-extremity revascularization. All revascularization procedures were completed at the time of initial aortic repair, with 8 of 15 cases receiving limb revascularization first and 7 of 15 cases receiving revascularization after proximal aortic repair. Two patients underwent endovascular stent repair, and 13 of 15 patients underwent open revascularization with femoral-femoral bypass.

The patients undergoing revascularization more often had underlying peripheral vascular disease (PVD) ($P = .004$) and associated pulse deficit ($P = .01$) at presentation (Table 3). Patients presenting with shock/tamponade were less likely to undergo revascularization. Adjusted odds ratios (ORs) based on the variables with P less than .2 on univariate analysis showed an increased likelihood of lower-extremity revascularization was associated with a pulse deficit (OR, 5.61, 95% CI, 0.99-24.04, $P = .02$), redo heart surgery (OR, 8.38, 95% CI, 1.02-68.90, $P = .05$), and PVD (OR, 3.73, 95% CI, 0.99-14.03, $P = .05$) (Table E5).

There were no significant differences in postoperative outcomes of in-hospital mortality and morbidity between patients with LEM undergoing revascularization and no revascularization except for a higher rate of lower-extremity fasciotomy after revascularization ($P = .003$). Of the 22 patients in the LEM group with new-onset renal

TABLE 2. Comparison of intraoperative and postoperative outcomes between patients with type A aortic dissection with and without concurrent lower-extremity malperfusion

Intraoperative variable	No LEM (n = 516)	LEM (n = 85)	*P* value
Cannulation strategy			.301
Aortic	426 (82.56)	64 (75.29)	
Subclavian	45 (8.72)	9 (10.59)	
Femoral	25 (4.84)	8 (9.41)	
Distal aorta			
Hemiarch replacement	333 (64.53)	40 (47.06)	.002
Total arch replacement	168 (32.56)	43 (50.59)	.001
Conventional elephant trunk	29 (5.62)	10 (11.76)	.033
Frozen elephant trunk	47 (9.11)	18 (21.18)	<.001
Cardiopulmonary bypass time (min)	199 ± 73.7	230 ± 69.8	<.001
Ischemic time (min)	135 ± 61.0	159 ± 60.9	.001
Antegrade cerebral perfusion time (min), median (IQR)	0.0 (0.0-25.0)	15.0 (0.0-37.0)	.004
Retrograde cerebral perfusion time (min), median (IQR)	19.0 (0.0-27.0)	20.0 (0.0-27.0)	.886
Low body HCA time	29.8 ± 14.9	32.9 ± 13.6	.140
Lowest core temperature	22.4 ± 4.47	20.7 ± 2.10	.003
RBC transfusion	203 (39.34)	49 (57.65)	.002
Total procedure time (h)	5.16 ± 2.07	6.07 ± 2.37	<.001
Proximal reconstruction			
Aortic valve resuspension	311 (60.3)	48 (56.5)	.508
Aortic valve replacement	32 (6.2)	5 (5.9)	1.00
Valve-sparing root replacement	104 (20.2)	18 (21.2)	.828
Complete aortic root replacement	96 (18.6)	15 (17.7)	.833
Mechanical valve implant	39 (7.6)	6 (7.1)	1.00
Bioprosthetic valve implant	55 (10.7)	9 (10.6)	.984
Postoperative outcome variables			
In-hospital mortality	53 (10.3)	16 (18.8)	.02
Total postoperative length of stay (d), median (IQR)	8 (6-13)	10.6 (6-18)	.12
Follow-up time (y), median (IQR)	4.6 (1.7-7.8)	4.6 (1.2-7.8)	.59
Mechanical ventilation time (h), median (IQR)	11.3 (5.9-27.4)	12.9 (6.0-52.0)	.097
Lower-extremity fasciotomy	1 (1.43)	4 (26.67)	.003
New-onset cerebrovascular accident	19 (3.7)	7 (8.2)	.06
New-onset atrial fibrillation	205 (39.7)	39 (45.9)	.28
Reexploration for bleeding	49 (9.5)	5 (5.9)	.28
New-onset renal failure requiring hemodialysis	46 (8.9)	22 (25.9)	<.001
Red blood cell transfusion	197 (38.2)	49 (57.7)	<.001

LEM, Lower-extremity malperfusion; *IQR*, interquartile range; *HCA*, hypothermic circulatory arrest; *RBC*, red blood cell.

failure requiring hemodialysis, 13 patients had recovery of renal function and 9 patients had evidence on long-term renal failure at the time of discharge. In the LEM group, there were 16 in-hospital mortalities. Of these, 5 of 16 were aortic related, 9 of 16 were related to shock/multiorgan system failure, and 2 of 16 were secondary to respiratory failure. Overall, 4 of 601 patients underwent reintervention on the descending aorta and 6 of 601 patients required reintervention on the proximal aorta. Three patients required reintervention for both proximal and descending aortas.

Comparison of preoperative CT imaging showed partial/complete thrombosis of the iliac artery ($P = .03$) and partial thrombosis of the false lumen ($P = .05$) more frequently in the revascularization group (Table 4). There were no lower-extremity amputations in the cohort. Estimated Kaplan–Meier survival was worse overall for patients with LEM undergoing revascularization compared with patients not undergoing revascularization ($P = .008$) (Figure 2). Univariable analyses are provided in Tables E4 and E6. In the LEM group, univariate factors associated with mortality included White race, hypertension, diabetes mellitus, and atrial fibrillation. After adjustment, the variables White race (HR, 0.37, 95% CI, 0.2-0.8, $P = .02$) and atrial fibrillation (HR, 5.0, 95% CI, 1.65-14.88, $P = .004$) remained significant (Table 5).

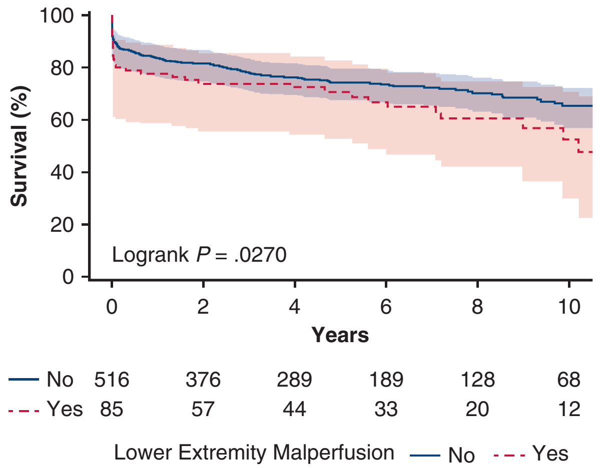


FIGURE 1. Survival in patients with TAAD presenting with concomitant LEM compared with no LEM.

DISCUSSION

Malperfusion syndromes in the setting of acute TAAD complicate clinical decision making because adverse outcomes occur more frequently in the setting of end-organ malperfusion. Fortunately, appropriate preoperative and intraoperative management of malperfusion syndromes can reduce mortality outcomes to 4% to 13%.[3] This study focuses specifically on peripheral malperfusion in TAAD and is one of the few to analyze outcomes in these patients undergoing revascularization versus conservative management (Figure 3).

Consistent with previous studies, our study found 14% of patients (85/601) with TAAD presented with LEM.[8-10] A majority of the patients with LEM in our study were managed with proximal aortic repair, and 18% (15/85) underwent lower-extremity revascularization. Others have reported a 0% to 3% amputation rate in this patient population.[9,11,12] In our cohort, no patients with LEM required amputation regardless of revascularization status.

Patient Demographics and Baseline Characteristics

Preoperative variables more commonly found in the LEM group included male gender, aortic valve insufficiency, depressed ejection fraction, baseline dialysis dependence, and concomitant malperfusion syndromes compared with patients with no LEM. These results are similar to those of Charlton-Ouw and colleagues,[13] who also found baseline characteristics of male gender, aortic valve insufficiency, renal dysfunction, and other malperfusion syndromes more often associated with ischemic limb on presentation. Unlike other studies that identify PVD to be associated with LEM, our study did not find the incidence of PVD was significantly different between groups.[1] However, when LEM was present, PVD was found to be associated with revascularization.

After propensity matching based on preoperative patient characteristics, differences in early postoperative outcomes were no longer significant. Results indicate that underlying patient factors may drive outcomes of TAAD repair irrespective of malperfusion.

In-hospital Morbidity and Mortality

Malperfusion syndromes can result in prolonged end-organ ischemia, setting off an inflammatory cascade that influences operative risk and postoperative healing.[12,14] Peripheral malperfusion has been extensively identified as a risk factor of mortality,[15,16] but Narayan and colleagues[17] go further to argue that the presence of malperfusion impacts mortality more than even the timing of intervention from symptom onset.

Our results demonstrate that patients with LEM more often required complex aortic repair with longer cardiopulmonary bypass and overall procedure times, and were more likely to be dependent on the ventilator, dialysis, and blood transfusions compared with patients without LEM. These perioperative factors further contribute to the capillary leak phenomenon and worsening shock, which likely contributed to the higher in-hospital mortality in the LEM group compared with no LEM. In the LEM group, undergoing revascularization did not influence in-hospital mortality. After adjustment, variables of White race and atrial fibrillation were significantly associated with increased mortality risk in the LEM group.

Long-term Survival

Geirsson and colleagues[18] demonstrated worse long-term survival for patients with malperfusion syndromes compared with patients without at 1, 5, and 10 years (68% vs 83% at 1 year, 54% vs 66% at 5 years, and 43% vs 46% at 10 years, respectively). When specifically analyzing survival in patients with TAAD with and without LEM, we also found survival was significantly worse in the LEM group (78% vs 84% at 1 year, 71% vs 74% at 5 years, and 52% vs 65% at 10 years, respectively) (Figure 1).

Similar to results published by Beck and colleagues,[8] within the LEM group, patients undergoing lower-extremity revascularization also had overall decreased late survival compared with patients not undergoing revascularization. This warrants further investigation because the perioperative outcomes were largely similar between these patients.

Role of Revascularization

When considering aortic dissections, some advocate aortic first intervention to restore flow in the true lumen to treat peripheral perfusion, whereas others prefer limb revascularization first.[11,19,20] Plotkin and colleagues[11] compared these 2 strategies and found the aortic first intervention led to successful LEM resolution in 72% of patients (26/36),

TABLE 3. Contingency table evaluating the association of lower-extremity revascularization to clinical variables

Variables	Frequency of lower-extremity revascularization	*P* value
Gender		.54
Male	12/61 (19.7)	
Female	3/24 (12.5)	
Race		.73
White	11/67 (16.4)	
Other	4/18 (22.2)	
Hypertension		.54
No	3/25 (12.0)	
Yes	12/60 (20.0)	
Diabetes mellitus		.60
No	13/78 (16.7)	
Yes	2/7 (28.6)	
Chronic lung disease		.14
No	12/77 (15.6)	
Yes	3/8 (37.5)	
Peripheral vascular disease		.004
No	4/52 (7.7)	
Yes	11/33 (33.3)	
Atrial fibrillation		.59
No	15/79 (19.0)	
Yes	0/6 (0.00)	
Coronary artery disease		.37
No	12/75 (16.0)	
Yes	3/10 (30.0)	
Redo heart surgery		.10
No	12/78 (15.4)	
Yes	3/7 (42.9)	
Aortic insufficiency moderate or greater		.78
No	8/41 (19.5)	
Yes	7/44 (15.9)	
Tamponade, rupture, or shock		.02
No	14/56 (25.0)	
Yes	1/29 (3.5)	
Current dialysis		.58
No	15/80 (18.8)	
Yes	0/5 (0.0)	
Cerebral malperfusion		.34
No	13/64 (20.3)	
Yes	2/21 (9.5)	
Coronary malperfusion		.58
No	15/80 (18.8)	
Yes	0/5 (0.0)	
Visceral malperfusion		1.00
No	13/70 (18.6)	
Yes	2/15 (13.3)	
Renal malperfusion		1.00
No	11/63 (17.5)	
Yes	4/22 (18.2)	
Previous lower-extremity intervention		.58
No	15/80 (18.8)	
Yes	0/5 (0.0)	
Pulse deficit		.01
No	6/60 (10.0)	
Yes	9/25 (36.0)	
Limb affected in LEM		.75
Left	7/23 (30.4)	
Right	5/24 (20.8)	
Both	2/8 (25.0)	

LEM, Lower-extremity malperfusion.

whereas limb first revascularization was successful in 50% (3/6). Charlton-Ouw and colleagues[13] found up to one-third of patients with LEM may require revascularization after the proximal aortic repair. However, these studies included both type A and type B aortic dissections, whereas our study focused on acute TAADs for which aortic repair was undertaken in an urgent fashion.

Norton and colleagues[20] recently reported their results of revascularization first approach in 25 patients presenting with LEM in TAAD. Of the 25, 16 patients underwent subsequent delayed open aortic repair, 3 were discharged without repair, and 6 patients died before undergoing proximal aortic repair. Postoperative outcomes were not significantly different in patients undergoing delayed aortic repair compared with patients without LEM, but the 24% (6/25) mortality rate in this subset raises concern regarding this approach.

Our results are in agreement with previous studies that have demonstrated proximal aortic repair successfully resolves LEM in the majority of cases.[8,9,11,21] In our cohort, all patients were treated with an aortic first approach with concomitant limb revascularization when there was clinical evidence of a threatened limb. Surgeon preference and assessment of patient factors drove decision making of treatment sequence for limb revascularization, with approximately half of the patients treated with the aortic repair first and the other half undergoing limb revascularization before aortic repair. No patients required reintervention or return to the operating room for further revascularization procedures or amputations after the index case. In-hospital mortality did not differ between patients with LEM undergoing revascularization and patients with no revascularization. Our results support that a patient-specific approach, focusing on the presenting patient factors, may aid in identification of patients who benefit most from revascularization at the time of initial intervention without impacting early survival.

TABLE 4. Imaging characteristics of type A aortic dissections presenting with lower-extremity malperfusion compared between those undergoing no revascularization and those undergoing revascularization

Variable	No lower-extremity revascularization (n = 70)	Lower-extremity revascularization (n = 15)	*P* value
Primary tear location			.40
Noncoronary sinus	14 (20.00)	0 (0.00)	
Left coronary sinus	2 (2.86)	0 (0.00)	
Right coronary sinus	2 (2.86)	1 (6.67)	
Sinotubular junction	15 (21.43)	2 (13.33)	
Ascending aorta	27 (38.57)	8 (53.33)	
Aortic arch	8 (11.43)	3 (20.00)	
Secondary arch tear	17 (24.29)	4 (26.67)	.85
Left main coronary artery	0 (0.00)	0 (0.00)	1.00
Right main coronary artery	2 (2.86)	0 (0.00)	1.00
Concomitant coronary artery bypass graft	6 (8.57)	3 (20.00)	.19
Extent of residual type B dissection			.39
0	24 (48.0)	6 (46.15)	
1 (Descending thoracic aorta)	2 (4.0)	1 (7.69)	
2 (Mesenteric)	0 (0.0)	1 (7.69)	
3 (Infrarenal)	2 (4.0)	0 (0.0)	
4 (Iliac)	22 (44.0)	5 (38.5)	
Missing	20	2	
Partial/complete thrombosis of iliac artery (missing)	19 (35.2) 16	6 (75.0) 7	.03
False lumen diameter greater than true lumen (missing)	46 (85.2) 16	8 (100) 7	.24
True lumen collapsed at level of paravisceral aorta (missing)	5 (9.6) 18	2 (25.0) 7	.23
Complete true lumen collapse/compression (missing)	6 (11.5) 18	7 (12.5) 7	1.00
False lumen patent (missing)	46 (85.2) 16	8 (100) 7	.58
False lumen partially thrombosed (missing)	17 (30.9) 15	6 (75.0) 7	.04
Pericardial effusion	6 (8.6)	2 (13.3)	.63

Factors Associated With Revascularization

There are few studies comparing patients with LEM and TAAD undergoing revascularization with no revascularization. In one study, Beck and colleagues[8] did not find differences in demographics or comorbidities between patients with TAAD requiring revascularization. However, in our study, consistent with Charlton-Ouw and colleagues,[13] we found peripheral arterial disease and pulse deficit were associated with the need for revascularization.

A patient presenting with tamponade or shock was less likely to undergo peripheral revascularization. Given the overall higher acuity and tenuous condition of the patient in this circumstance, it is not unexpected that LEM was observed rather than intervened upon.

Anatomic and dissection characteristics based on CT imaging are depicted in Table 4. Beck and colleagues[8] have also analyzed imaging characteristics in patients with TAAD and LEM. In contrast to Beck and colleagues' results, the extent of the dissection did not influence the need for revascularization in our study. Iliac artery thrombosis was similarly more common in the revascularization group. A new finding in our study was that patients with false lumen thrombosis also were more likely to require revascularization.

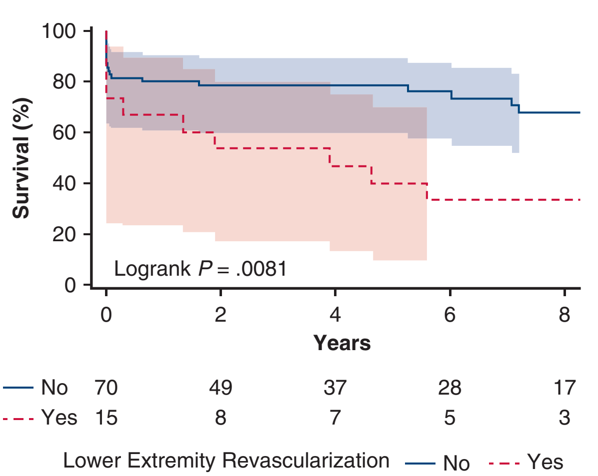


FIGURE 2. Survival in patients with TAAD with LEM undergoing lower-extremity revascularization compared with no revascularization.

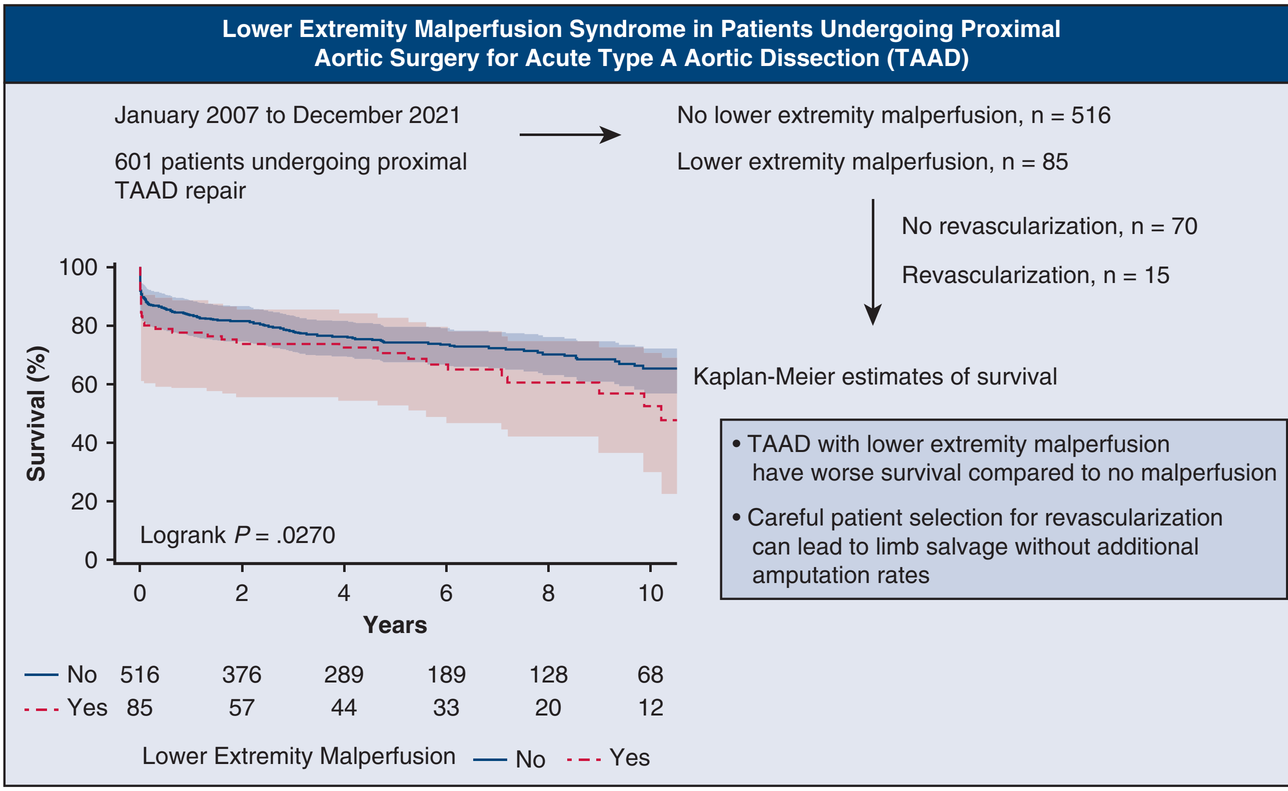


FIGURE 3. Graphical abstract.

Fattouch and colleagues[22] found a patent false lumen to be associated with the need for re-treatment and late mortality after proximal TAAD repair. Our study did not find false lumen patency to be associated with revascularization need at the time of proximal aortic repair. However, this study was limited by the number of patients undergoing revascularizations, and available CT imaging data such that association of imaging factors and mortality could not be reliably attained.

TABLE 5. Adjusted hazard ratio of mortality (based on the univariate model *P* < .2) in patients with type A aortic dissection and lower-extremity malperfusion

Variables	Hazard ratio (95% CI)	*P* value
White	0.37 (0.16-0.83)	.02
Hypertension	0.40 (0.82-7.01)	.11
Diabetes mellitus	1.34 (0.49-3.69)	.57
Chronic lung disease	1.63 (0.56-4.75)	.37
Malperfusion syndrome: coronary	2.37 (0.75-7.52)	.14
Aortic insufficiency moderate or greater	0.54 (0.25-1.15)	.11
Atrial fibrillation	4.96 (1.65-14.88)	.004

Harrell C statistic 0.751. *CI*, Confidence interval.

The focus of this study was on proximal aortic repair with or without peripheral revascularization. However, alternative options such as antegrade stent deployment in the descending aorta at the time of proximal aortic repair have been demonstrated by Preventza and colleagues,[23,24] with less short-term operative mortality and improved false lumen remodeling and overall survival at midterm follow-up. Although the optimal approach warrants further investigation, the clinical strategy should be tailored to the patient's presentation.[25]

Concomitant Malperfusion Syndromes

Concomitant mesenteric, coronary, and cerebral malperfusion can result in more lethal implications compared with lower-extremity ischemia, yet malperfusion syndromes are often used as a composite variable to calculate risk in TAAD outcome studies.[5,23,24,26] Jaffar-Karballai and colleagues[10] compared multiple studies on this topic, finding that limb malperfusion had a higher incidence anywhere from 6% to 53%, but mortality in these patients ranged from 3% to 24%. Although mesenteric, coronary, and cerebral malperfusion syndromes were often associated with higher mortality rates of 20% to 75%. Charlton-Ouw and colleagues[13] reported patients requiring peripheral limb revascularization were more likely to have associated mesenteric ischemia and overall worse 10-year survival (22% vs 59%, $P < .001$).

In this study, renal, visceral, and cerebral malperfusion syndromes were more often present in the LEM group ($P < .001$). Concomitant malperfusion syndrome was not independently associated with mortality. Specifically, we also did not find that any particular concomitant malperfusion syndrome was associated with the need for revascularization.

Study Limitations

A limitation of the study is its retrospective nature with inherent treatment and hospital center-specific bias. Comfort level among surgeons may have varied and influenced the decision to pursue lower-extremity revascularization at the time of proximal aortic repair. There was not adequate data to determine if timing from symptom onset to operative repair influenced outcomes. The low number of patients undergoing revascularization overall was a limitation to the type of statistical analyses that could be reliably performed.

It should be acknowledged that the study data are based on electronic medical record review and a single-center database. After the index operation, patient presentation to hospitals outside of our health system could have contributed to missing follow-up data points and limited study outcomes.

This study focused on imaging characteristics as determinants of revascularization. Additional factors that could determine Rutherford grade of limb ischemia or biochemical markers were not available for study but could have influenced revascularization decision. Components of variables measured by CT imaging were missing in up to 30% of patients (25/85). Patients with TAAD often were diagnosed elsewhere and transferred to our institution, and although imaging reports were available through electronic medical records, the CT scans were at times transferred on a disc without being uploaded to a permanent location. Thus, with approximately one-third of patients missing imaging data, the results should be interpreted cautiously and warrant further investigation.

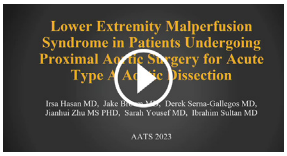
CONCLUSIONS

LEM complicates TAAD presentation and management. Male gender, aortic insufficiency, low ejection fraction, and dialysis dependence were found more often in patients presenting with LEM compared with TAAD without LEM. These factors translated into a more complex intraoperative and postoperative hospital course, and worse survival compared with patients without LEM. Concomitant malperfusion syndromes were not associated with worse prognosis in this study.

Although LEM resolved for a majority of patients after proximal aortic repair, those who required revascularization were more likely to present with a pulse deficit and a history of PVD. Iliac artery and false lumen thrombosis were more often associated with the need for revascularization. There were no differences in postoperative morbidity and in-hospital mortality between patients undergoing revascularization versus no revascularization with 100% limb preservation.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://www.aats.org/resources/outcomes-of-lower-extremity-malperfusion-syndrome-in-patients-undergoing-proximal-type-a-aortic-dissection-repair.



Conflict of Interest Statement

I.S. receives institutional research support from Abbott, Artivion, Boston Scientific, Medtronic, and AtriCure, and consults for Medtronic Vascular. None of these are related to this manuscript. All other authors reported no conflicts of interest.

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

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Key Words: aortic dissection, aortic repair, limb ischemia, malperfusion syndrome, peripheral vascular disease, revascularization

TABLE E1. Demographic and clinical variables in those with or without lower-extremity malperfusion in propensity score–matched samples

Variable	No LEM (n = 75)	LEM (n = 75)	Absolute standard median deviation	*P* value
Age (y)	60.6 ± 14.8	60.5 ± 10.4	0.008	.934
Female	22 (29.33)	24 (32.00)	0.058	.723
White	57 (76.00)	59 (78.67)	0.064	.697
Body mass index (kg/m^2)	30.5 ± 7.79	30.1 ± 6.84	0.054	.753
Hypertension	59 (78.67)	52 (69.33)	0.214	.193
Diabetes mellitus	6 (8.00)	6 (8.00)	0	1.000
Chronic lung disease	8 (10.67)	7 (9.33)	0.045	.786
Peripheral vascular disease	23 (30.67)	30 (40.00)	0.196	.232
Atrial fibrillation	10 (13.33)	6 (8.00)	0.173	.290
Coronary artery disease	13 (17.33)	10 (13.33)	0.111	.497
Redo heart surgery	11 (14.67)	7 (9.33)	0.165	.315
Aortic insufficiency moderate or greater	31 (41.33)	39 (52.00)	0.215	.190
Ejection fraction	53.1 ± 10.3	52.6 ± 13.5	0.042	.826
Tamponade, rupture, or shock	31 (41.33)	26 (34.67)	0.138	.400
Current dialysis	6 (8.00)	3 (4.00)	0.169	.302
Preoperative hematocrit	37.0 ± 6.60	39.2 ± 6.94	0.325	.100
Preoperative creatinine level	1 (1-2)	1 (1-1)	NA	.049
Type of malperfusion syndrome				
Cerebral	15 (20.00)	17 (22.67)	0.055	.690
Coronary	5 (6.67)	4 (5.33)	0.056	.731
Visceral	12 (16.00)	8 (10.67)	0.157	.337
Renal	14 (18.67)	12 (16.00)	0.071	.666

LEM, Lower-extremity malperfusion; *NA*, not available.

TABLE E2. Postoperative outcomes compared with or without lower-extremity malperfusion in propensity score–matched sample

Variable	No LEM (n = 75)	LEM (n = 75)	*P* value
In-hospital mortality	9 (12.00)	14 (18.67)	.26
Total postoperative length of stay (d)	15.9 ± 17.9	13.9 ± 13.6	.43
Follow-up time (y), median (IQR)	3.74 (1.27-6.1)	4.58 (1.18-7.7)	.62
Mechanical ventilation time (h)			
Mean ± SD	56.2 ± 99.4	84.4 ± 192.0	.28
Median (IQR)	12.35 (7.35-44.0)	12.83 (5.77-38.1)	.10
Postoperative pneumonia	10 (13.33)	9 (12.00)	.81
New-onset cerebrovascular accident	4 (5.33)	7 (9.33)	.35
Postoperative atrial fibrillation	36 (48.00)	33 (44.00)	.62
Reexploration for excessive bleeding	11 (14.67)	5 (6.67)	.11
New-onset renal failure requiring hemodialysis	11 (14.67)	16 (21.33)	.29
Red blood cell transfusion	33 (44.00)	44 (58.67)	.07

LEM, Lower-extremity malperfusion; *IQR*, interquartile range; *SD*, standard deviation.

TABLE E3. Multivariable Cox proportional-hazards regression model for 1-year survival in all patients undergoing type A aortic dissection repair

Variable	Hazard ratio (95% CI)	*P* value
LEM	1.42 (0.84-2.40)	.19
Gender (female)	1.48 (0.98-2.25)	.06
Age (y)	1.06 (1.04-1.08)	<.001
Race, White	0.45 (0.27-0.73)	.001
Diabetes mellitus	1.98 (1.17-3.33)	.01
Ejection fraction	0.98 (0.96-0.99)	.005
Tamponade, rupture, or shock	1.61 (1.08-2.41)	.02
Dialysis	2.68 (0.92-7.76)	.07
Coronary malperfusion	2.96 (1.66-5.27)	<.001
Total arch repair	3.39 (2.20-5.20)	<.001
Coronary artery disease	1.44 (0.87-2.39)	.16

CI, Confidence interval; *LEM*, lower-extremity malperfusion.

TABLE E4. Univariable logistic regression for lower-extremity revascularization

Variable	OR (95% CI)	*P* value
Age (y)	0.98 (0.93-1.03)	.37
Female	0.65 (0.17-2.39)	.51
White	0.66 (0.19-2.31)	.51
Body mass index (kg/m^2)	0.97 (0.88-1.06)	.46
Hypertension	1.66 (0.45-6.13)	.45
Diabetes mellitus	2.21 (0.40-12.12)	.36
Chronic lung disease	3.34 (0.71-15.66)	.13
Peripheral vascular disease	5.51 (1.64-18.53)	.006
Atrial fibrillation	0.32 (0.01-7.52)	.47
Coronary artery disease	2.37 (0.55-10.25)	.25
Redo heart surgery	4.14 (0.83-20.76)	.08
Aortic insufficiency moderate or greater	0.79 (0.26-2.37)	.67
Ejection fraction	0.98 (0.95-1.02)	.67
Tamponade, rupture, or shock	0.15 (0.03-0.91)	.04
Current dialysis	0.38 (0.02-9.62)	.56
Malperfusion syndrome		
Cerebral	0.49 (0.11-2.14)	.34
Coronary	0.38 (0.02-9.62)	.34
Visceral	0.79 (0.17-3.59)	.76
Renal	1.11 (0.32-3.81)	.87
Previous lower-extremity intervention	0.38 (0.02-9.62)	.56
Pulse deficit	4.83 (1.52-15.33)	.008
Limb affected in LEM		
Left (ref)	1	
Right	0.62 (0.17-2.29)	.47
Both	0.86 (0.14-5.02)	.85

OR, Odds ratio; *CI*, confidence interval; *LEM*, lower-extremity malperfusion.

TABLE E5. Adjusted odds ratios of lower-extremity revascularization estimated by penalized maximum likelihood

Variable	OR (95% CI)	*P* value
Chronic lung disease	7.04 (0.91-54.73)	.062
Peripheral vascular disease	3.73 (0.99-14.03)	.052
Paulse deficit	5.61 (1.31-24.04)	.020
Tamponade, rupture, or shock	0.16 (0.02-1.14)	.067
Redo heart surgery	8.38 (1.02-68.90)	.048

C statistics 0.897. Variables selection: $P < .2$ based on univariate analysis. *OR*, Odds ratio; *CI*, confidence interval.

TABLE E6. Univariable Cox regression for mortality in patients with type A aortic dissection and lower-extremity malperfusion

Variable	HR (95% CI)	*P* value
Age (y)	1.01 (0.97-1.04)	.77
Female	1.59 (0.77-3.29)	.21
White	0.35 (0.16-0.75)	.007
Body mass index (kg/m^2)	1.02 (0.98-1.07)	.32
Hypertension	3.20 (1.17-8.75)	.02
Diabetes mellitus	2.42 (1.01-5.79)	.05
Chronic lung disease	2.23 (0.87-5.72)	.10
Peripheral vascular disease	1.08 (0.54-2.15)	.82
Atrial fibrillation	7.27 (2.67-19.78)	<.001
Coronary artery disease	1.54 (0.61-3.91)	.36
Redo heart surgery	1.38 (0.50-3.86)	.54
Aortic insufficiency moderate or greater	0.54 (0.27-1.07)	.08
Ejection fraction	0.99 (0.96-1.02)	.49
Tamponade, rupture, or shock	1.13 (0.54-2.35)	.75
Current dialysis	1.65 (0.44-6.19)	.46
Malperfusion syndrome		
Cerebral	1.02 (0.46-2.26)	.96
Coronary	2.49 (0.90-6.09)	.08
Visceral	1.39 (0.61-3.18)	.43
Renal	0.96 (0.45-2.07)	.92
Previous lower-extremity intervention	0.93 (0.18-4.96)	.93
Pulse deficit	1.25 (0.61-2.54)	.54
Limb affected in LEM		
Left (ref)	1	
Right	0.57 (0.20-1.62)	.29
Both	1.59 (0.52-4.87)	.41

HR, Hazard ratio; *CI*, confidence interval; *LEM*, lower-extremity malperfusion.