Comparative analysis of the treatment of asymptomatic and symptomatic complex aortic aneurysms

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Abstract

Background: Fenestrated-Branched Endovascular Aortic Repair (F-BEVAR) is one of the new treatments that build on and customizes existing endograft technology for patients with complex aortic aneurysm. However, data is limited, and further research is needed. Therefore, the objective of this study is to identify the differences in outcomes for asymptomatic and symptomatic patients treated with endovascular intervention.

Methods: To investigate this objective, we studied all the F-BEVAR procedures in the thoracic and complex endovascular aortic repair registry which is part of the Vascular Quality Initiative database. These excluded patients coming in with an aortic rupture. The primary outcome is survival. The secondary outcomes include time-to-first reintervention, ICU/hospital stay, and other post-operative factors. We produced Kaplan-Meier curves for the time-to-event outcomes. For the primary outcome, we fitted univariate and multivariate Cox proportional hazards models. For the binary secondary outcomes, we fitted univariate and multivariate logistic regression models using generalized estimating equations with working independence. The multivariate models adjusted for confounders based on expert consultation. All models clustered on center. A log-rank and Wald test was used to compare theses outcomes.

Results: There were a total of 3757 patients who were treated with F-BEVAR (Asymptomatic: 3315, Symptomatic: 442). Most of these patients are elderly males. Based on a cox-proportional hazards model, the estimated hazard of mortality is 84% higher for symptomatic patients compared to asymptomatic patients adjusting for the appropriate confounders (HR = 1.84, 95% CI for hazard ratio: 1.41-2.41; $p < 0.001$). The non-reintervention rate is similar between the asymptomatic and symptomatic patients (log-rank test, $p = 0.24$). Based on multivariate logistic regression models, the estimated odds for ICU stay, post-treatment of all branches, post-op complications, post-op dialysis, post-op length of hospital stay, post-op respiratory, post-op spinal ischemia, re-intervention during the same hospitalization, and total length of hospital stay differs between symptomatic and asymptomatic patients (Wald $p \leq 0.05$).

Conclusion: The mortality for symptomatic patients is higher compared to asymptomatic patients. The odds for longer hospital stays and post-operative complications/factors are higher for symptomatic patients, too. Thus, it is imperative to screen and treat patients with complex aortic aneurysms early before they begin to present urgent or emergent symptoms.

1. Background

An abdominal aortic aneurysm is an enlargement of the aorta at the level of the abdomen. Risk factors for this condition include males, hypertension, older age, tobacco use, and family history. This disease is quite common, there are more than 3 million cases per year in the United States.[3] About 13,000 Americans die annually due to rupture of the aortic aneurysm.[5] This condition is treated by open aortic repair or endovascular management which involves repair by a stent. In some patients, the aneurysm involves the aorta in the chest and abdomen at the level of vital branches to the intestines and kidneys, called thoraco-abdominal aortic aneurysms (TAAA), a specific type of complex aortic aneurysm (complex AA).

TAAA is one of the most challenging problems for vascular surgeons due to limited treatments. Stent graft treatment is not available for TAAA patients, because each patient has a unique positioning of these critical blood vessels. The other treatment option is traditional open surgery repair which is associated with 20% mortality. Due to this increased mortality rate, many patients with complex aortic aneurysms have been turned down for treatment. However, less invasive endovascular surgery has been developed as a new treatment option for these patients.[5]

At the University of Washington, the Division of Vascular Surgery has developed investigational treatment programs for aortic aneurysms. Fenestrated-Branched Endovascular Aortic Repair (F-BEVAR) is one of the new treatments that build on and customizes existing endograft technology for patients with complex aortic aneurysm, which will develop custom devices for each patient based on their unique anatomy. Most patients with complex aortic aneurysms exhibit no symptoms. However, for symptomatic patients, aneurysms are typically large with a higher risk for rupture, which is associated with a higher mortality rate. Open repair might be a high-risk procedure for symptomatic patients. F-BEVAR provides a safer alternative to open aortic aneurysm repair in appropriately selected patients at high volume centers and allows treatment for patients who would otherwise have no options.[5]

However, data is limited, and further research is needed as there are many questions about this new technology such as what the long-term and short-term outcomes look like in subgroups. Specifically, how do these outcomes compare between symptomatic and asymptomatic patients who undergo the F-BEVAR procedure? This information will help surgeons and physicians decide the best course of treatment and provide prognostics based on specific characteristics for their patients. Therefore, the objective of this study is to identify the differences in outcomes for asymptomatic and symptomatic patients treated with endovascular intervention.

2. Methods

2.1 Data Source

To investigate this objective, we used the Vascular Quality Initiative (VQI) database.[2] The VQI is a multi-center database with more than 200 variables. Its 14 registries contain demographic, clinical, procedural and outcome data from more than 900,000 vascular procedures performed in the United States and Canada.

The specific registry used was the thoracic and complex endovascular aortic repair (EVAR) procedure. The thoracic and complex EVAR dataset captures more than 25,000 procedures starting in 2010 to 2022. It records variables such as patient demographics, comorbidities, operative and anatomic differences, and short-term and long-term outcomes following the procedures. In addition to these variables, data was collected on the center where the procedure was performed.

2.2 Population of Interest

The population of interest is patients with asymptomatic and symptomatic complex aortic aneurysms treated with F-BEVAR. We excluded patients coming in with an aortic rupture. In addition to including patients presenting no symptoms, we defined patients as asymptomatic when their procedure was labeled elective meaning it was a planned procedure. Similarly, in addition to including patients presenting symptoms, we defined patients as symptomatic when their procedure was labeled urgent or emergent meaning the procedure was given within 24 or 4 hours of the patients presenting symptoms, respectively.

2.3 Key Variables: Covariates, Confounders, & Outcomes

The primary covariate of interest is the variable indicating asymptomatic or symptomatic patients. Some categorical variables with multiple categories were re-coded as binary to simplify the results. The primary outcome is survival. The secondary outcomes include time-to-first reintervention for patients with long-term follow-up, total length of stay (LOS) (>7 days or <= 7 days), post-operative length of stay (LOS) (>7 days or <= 7 days), length of stay in the intensive care unit (>4 or <= 4 days), post-operative glomerular filtration rate (GFR) (>= 50% in GFR reduction or <50%), post-operative intestinal ischemia (yes or no), post-operative cerebrovascular stroke (yes or no), post-operative spinal ischemia (yes or no), post-operative complications (yes or no), post-operative dialysis (yes or no), post-operative leg ischemia/emboli (yes or no), post-operative respiratory complications (yes or not), re-intervention during the same hospitalization (yes or no), and post-operative treatment of all aortic branches (yes or no). Total LOS is the length of stay in days between the admission date and discharge date. Post-op LOS is the length of stay in days between the procedure date and discharge date.

To account for confounding, selected covariates were adjusted for in the multivariate models. Confounders were determined based on expert consultation from surgeons at the University of Washington - Division of Vascular Surgery. These confounders include age, sex, smoking history, prior aortic procedures, history of congestive heart failure, pre-operative dialysis, pathology,

type of TAAA extent (Juxtarenal AAA or not), procedure performed via arm or neck arteries, post-operative spinal drain placement, occlusion of the celiac branch, occlusion of the renal branch, and pre-operative chronic kidney disease stage. Not all the multivariate models included all these confounders, because these selected covariates are identified as confounders depending on the type of outcome. Furthermore, all the multivariate models for the primary and secondary outcomes did adjust for age, sex, smoking history, prior aortic procedures, history of congestive heart failure, pathology, and type of TAAA extent. (See **Table S1** in the appendix for additional variables adjusted for in the respective multivariate model.)

2.4 Statistical Analysis

First, we conducted univariate analyses testing the associations between the primary covariate of interest and demographics, clinical, operative, and procedure outcomes. Continuous outcomes were evaluated using Welch's two-sample t-test. Categorical outcomes were evaluated using Pearson's chi-square test. (See **Table S2-S4** in the appendix.)

For the primary and secondary outcomes, time-to-death and time-to-first reintervention, we produced Kaplan-Meier curves to describe the survival and non-reintervention for both groups. A log-rank test was used to compare theses outcomes. For the primary outcome, we fitted a univariate Cox proportional hazards model to estimate the hazard ratio of the primary covariate. After checking assumptions and running diagnostics, we built a stratified multivariate Cox proportional hazards model stratifying on sex and adjusting for the appropriate confounders. We did not fit Cox proportional hazards models for the secondary outcome, time-to-first reintervention, because not all patients had long-term follow-up records resulting in missing data. Moreover, we built univariate and multivariate models for the binary secondary outcomes using logistic regression. For these adjusted models, a Wald test was used to test the statistical significance between the primary covariate and these outcomes.

Furthermore, all regression methods accounted for clustering by center. Clustering on center is necessary to adjust for differences in the volume of procedures performed in each center. For the Cox proportional hazards model, we used the marginal approach to obtain these standard errors and perform hypothesis testing that accounts for correlation within centers.[1] For the logistic regression models, we used generalized estimating equations (GEE) with working independence to compute the robust standard errors that account for correlation within centers.

The threshold to determine statistical significance was 0.05. Statistical analysis was performed using R version 4.1.2.

3. Results

3.1 Descriptive Statistics

After applying the inclusion and exclusion criteria for our population of interest, there are a total of 3757 patients treated with F-BEVAR (**Table 1**). Among these patients, about 88% (3315) are asymptomatic and about 12% (442) are symptomatic. Most of these patients are elderly males. Specifically, the average age of these patients is 73 years old and about 95% are 60 years or older. Also, the average age between the two groups is similar with the asymptomatic patients being slightly older. About 13% of the overall patients experienced the event (mortality) with the percentage of the symptomatic patients (21%) experiencing the event more compared to the percentage of asymptomatic patients (12%). Follow-up days are the number of days between the procedure date and the last known date of contact. The median follow-up time for the asymptomatic patients is over a year (398 days) while it is under a year for the symptomatic patients (309 days).

Variable	Asymptomatic (N=3315)	Symptomatic (N=442)	Overall (N=3757)
Age			
Mean (SD)	73.5 (7.89)	70.8 (10.1)	73.2 (8.23)
Age Category			
<50	19 (0.6%)	14 (3.2%)	33 (0.9%)
>79	749 (22.6%)	87 (19.7%)	836 (22.3%)
50-59	106 (3.2%)	45 (10.2%)	151 (4.0%)
60-69	856 (25.8%)	115 (26.0%)	971 (25.8%)
70-79	1585 (47.8%)	181 (41.0%)	1766 (47.0%)
Sex			
Female	800 (24.1%)	177 (40.0%)	977 (26.0%)
Male	2515 (75.9%)	265 (60.0%)	2780 (74.0%)
Mortality			
Yes	390 (11.8%)	94 (21.3%)	484 (12.9%)
No	2925 (88.2%)	348 (78.7%)	3273 (87.1%)
Follow-Up Days			
Median [IQR]	398 [15, 1046]	309 [11, 660]	391 [13, 1015]

Table 1. A comparison of baseline demographic characteristics for asymptomatic versus symptomatic patients who undergo the F-BEVAR procedure.

3.2 Primary Outcome

Based on the Kaplan-Meier curves, the survival rate was higher for asymptomatic than symptomatic patients (log-rank test, $p < 0.001$) (**Figure 1**). Also, it appears most events (mortality) happened within the first two years. At one year, there's a 12% difference in the estimated survival rate between these two groups (**Table 2**). At five and 10 years, there's a 13% and 19% difference in the estimated survival rate, respectively, between these two groups. Based on a univariate Cox proportional hazards model, the hazard of mortality in the symptomatic group is estimated to be 2.06 times the hazard of mortality in the asymptomatic group (95% CI for hazard ratio: 1.65-2.58). Based on a stratified multivariate cox-proportional hazards model stratifying on sex, the estimated hazard of mortality is 84% higher for symptomatic patients compared to asymptomatic patients adjusting for the appropriate confounders (HR = 1.84, 95% CI for hazard ratio: 1.41-2.41; $p < 0.001$).

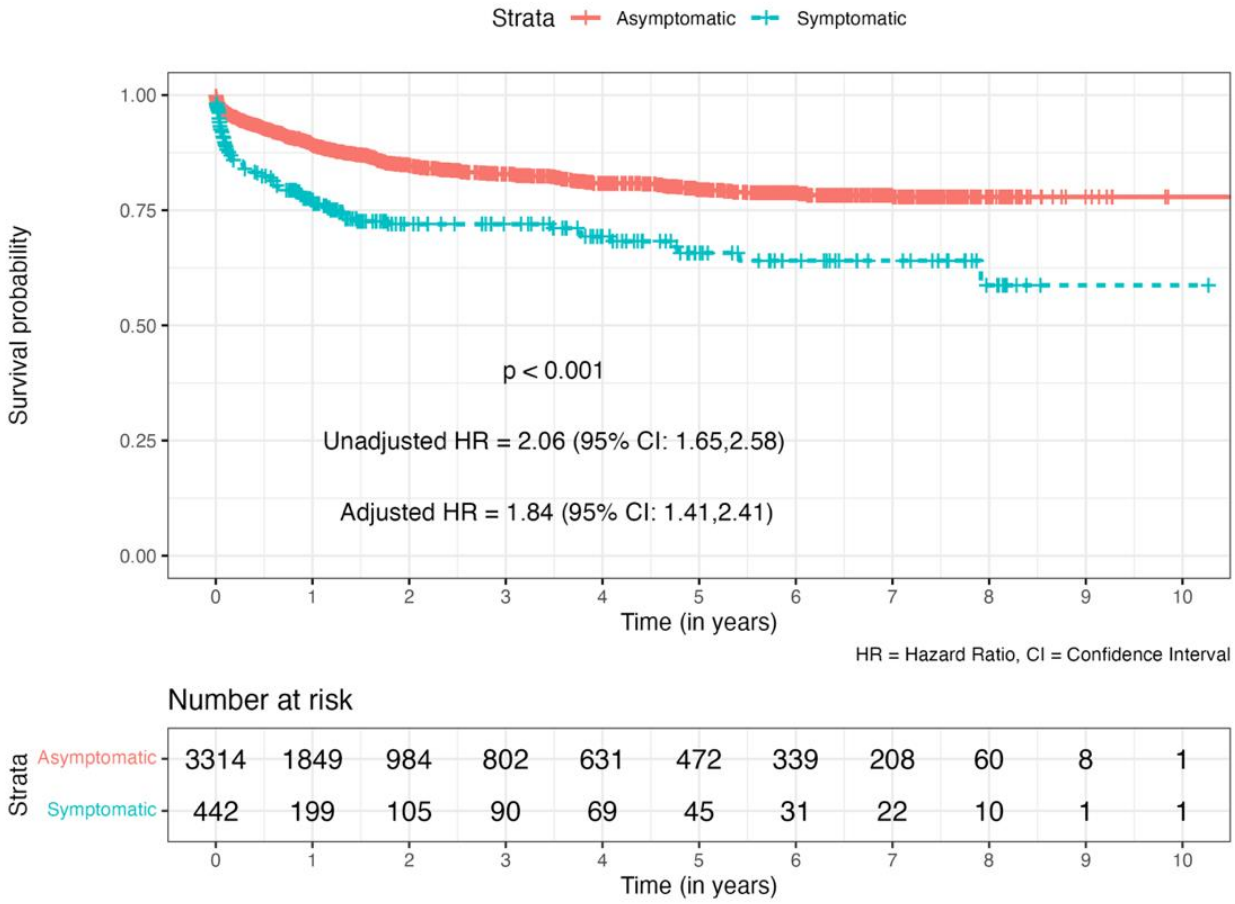

Figure 1. A comparison of Kaplan-Meier curves for asymptomatic versus symptomatic patients who undergo the F-BEVAR procedure for the survival outcome.

Year	Asymptomatic	Symptomatic
1	0.89 (95% CI: 0.88-0.9)	0.77 (95% CI: 0.72-0.81)
5	0.79 (95% CI: 0.77-0.82)	0.66 (95% CI: 0.58-0.72)
10	0.78 (95% CI: 0.75-0.8)	0.59 (95% CI: 0.46-0.7)

Table 2. Using Kaplan-Meier estimates, the estimated survival rate and 95% confidence intervals (CIs) at the corresponding year for the two groups.

3.3 Secondary Outcomes

Based on the Kaplan-Meier curves, the non-reintervention rate is similar between the asymptomatic and symptomatic patients (log-rank test, p = 0.24) (**Figure 2**). At one year, there's a 3% difference in the estimated non-reintervention rate between these two groups (**Table 3**). At five years, there's a 1% difference in the estimated non-reintervention rate between these two groups.

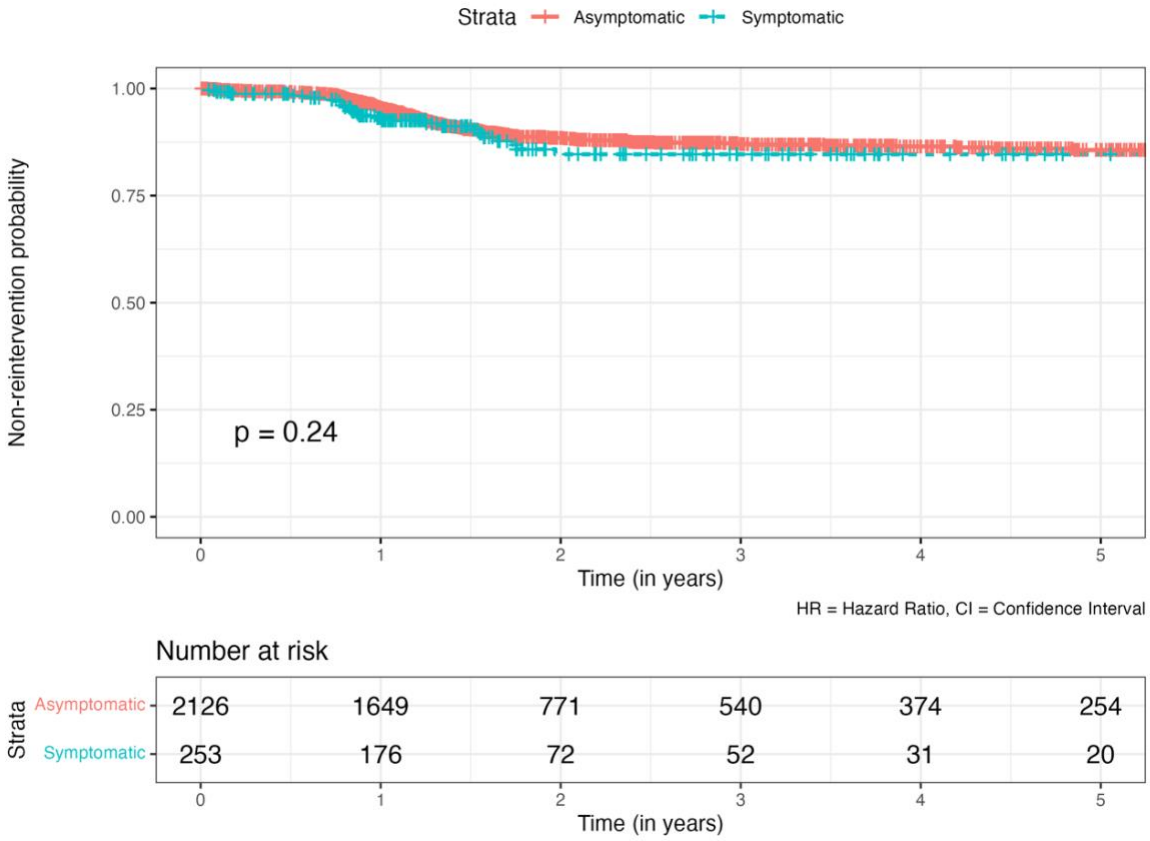

Figure 2. A comparison of Kaplan-Meier curves for symptomatic versus asymptomatic patients who undergo the F-BEVAR procedure for the time-to-first reintervention outcome.

Year	Asymptomatic	Symptomatic
1	0.96 (95% CI: 0.95-0.96)	0.93 (95% CI: 0.9-0.97)
5	0.86 (95% CI: 0.84-0.88)	0.85 (95% CI: 0.79-0.91)

Table 3. Using Kaplan-Meier estimates, the estimated non-reintervention rate and 95% confidence intervals (CIs) at the corresponding year for the two groups.

Based on the multivariate logistic regression models, for all binary secondary outcomes, the symptomatic patients have higher estimated odds than the asymptomatic patients adjusting for the appropriate confounders (**Figure 3**). The estimated odds for ICU stay, post-treatment of all branches, post-op complications, post-op dialysis, post-op length of hospital stay, post-op respiratory, post-op spinal ischemia, re-intervention during the same hospitalization, and total length of hospital stay differs between symptomatic and asymptomatic patients (Wald $p \leq 0.05$). (See **Figure S1** in appendix for the results of the univariate logistic regression models.)

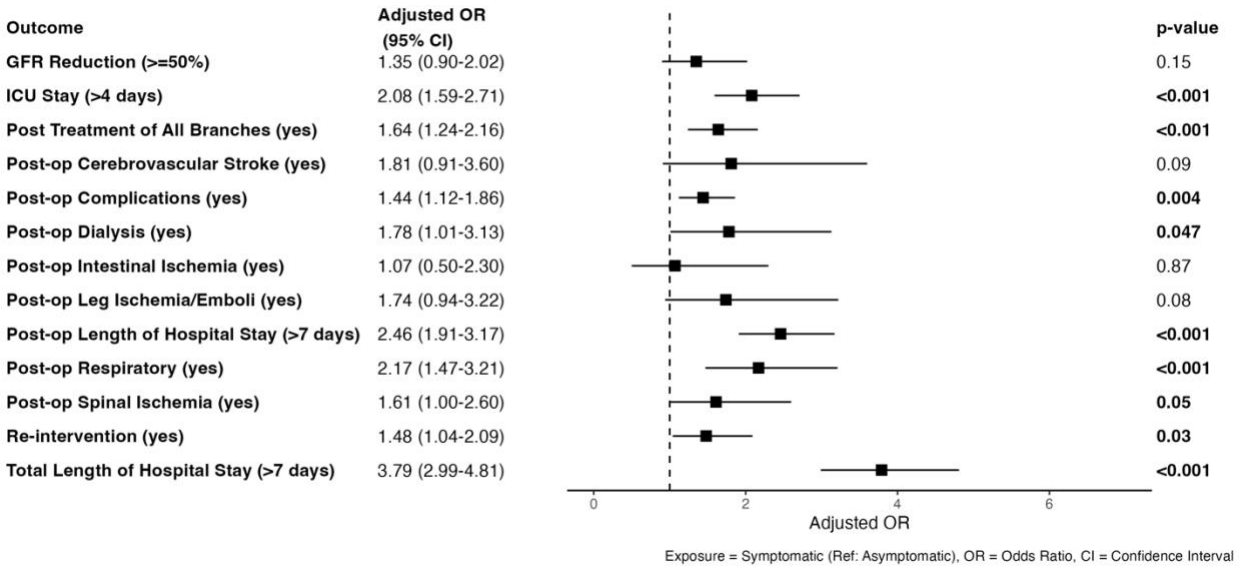

Figure 3. A forest plot presenting the adjusted odds ratio estimates with 95% CIs of symptomatic patients for the binary secondary outcomes.

4. Discussion & Conclusions

This study found that there is a significant difference in survival between patients with asymptomatic and symptomatic complex aortic aneurysms treated with F-BEVAR. The mortality for symptomatic patients is higher compared to asymptomatic patients. Additionally, the odds for longer hospital stays and post-operative complications/factors are higher for symptomatic patients, too. Thus, it is imperative to screen and treat patients with complex aortic aneurysms early before they begin to present urgent or emergent symptoms. Furthermore, due to these

significant results, it is important for the cost of F-BEVAR procedures be widely covered under more insurance policies. This will allow patients to have access to the care they need and help prevent these outcomes by providing treatment before the onset of symptoms.

4.1 Limitations

There are some limitations to this study. Firstly, the VQI database limitations include coding errors, missing data for long-term follow-up patient records, and self-reported data at each site. This is also a retrospective analysis of all hospitals participating in the VQI and therefore, the results do not represent the whole population. Moreover, the results are explorative and descriptive in nature; so, this does not imply a causal relationship and caution must be taken when interpreting the results. Lastly, it is possible other variables were not accounted for in the statistical models.

4.2 Next Steps

Despite these limitations, the results are worthy of further study. Therefore, we will work to publish these results in the Journal of Vascular Surgery. Then, this study will be submitted to and presented at the annual Western Vascular Society Meeting. Finally, based on this study and the results, further subgroup analyses are necessary and will be conducted since there appears to be a disparity between sex and racial groups.

5. References

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[6] Zettervall, Sara L et al. “Regional variation exists in patient selection and treatment of abdominal aortic aneurysms.” *Journal of vascular surgery* vol. 64,4 (2016): 921-927.e1. doi:10.1016/j.jvs.2016.02.036

Appendix

Table of Supplementary Tables/Figures

Figure S1. Forest Plot of Univariate Models for the Binary Secondary Outcomes

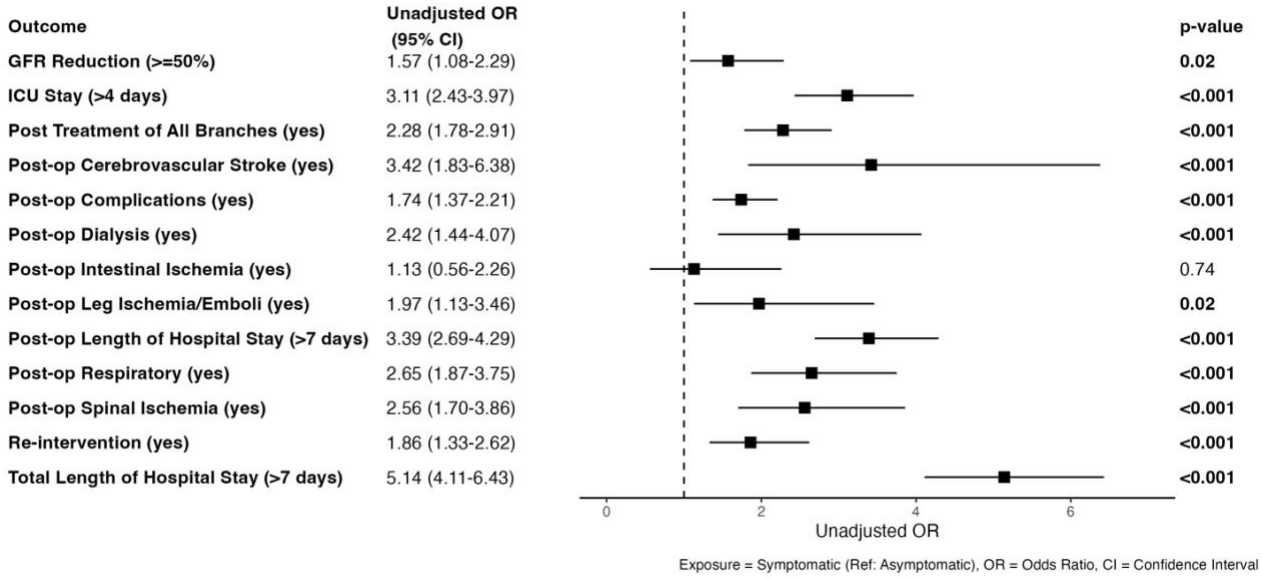

Table S1. Additional Confounders

All the multivariate models for the primary and secondary outcomes adjusted for age, sex, smoking history, prior aortic procedures, history of congestive heart failure, pathology, and type of TAAA extent. In addition to these variables, the variables below were also adjusted for in the respective multivariate model:

Outcome	Variable						
	Pre-op Dialysis	Pre-op Chronic Kidney Disease Stage	Number of Treated Renals	Arm/ Neck Access	Post-op Spinal Drain Placement	Celiac Occlusion	Renal Occlusion

All-Cause Mortality	✓						
GFR Reduction		✓	✓				
ICU Stay	✓						
Post Treatment of All Branches	✓						
Post-op Cerebrovascular Stroke	✓			✓			
Post-op Complications	✓						
Post-op Dialysis	✓						✓
Post-op Intestinal Ischemia	✓						
Post-op Leg Ischemia/ Emboli	✓						
Post-op Length of Hospital Stay	✓						
Post-op Respiratory	✓						
Post-op Spinal Ischemia	✓				✓	✓	
Re-intervention	✓						
Total Length of Hospital Stay	✓						

Table S2. Comparison of Baseline Characteristics

Variable	Asymptomatic (N=3315)	Symptomatic (N=442)	P-value
Age			
Mean (SD)	73.5 (7.89)	70.8 (10.1)	<0.001
Median [Min, Max]	74.0 [0, 90.0]	72 [33.0, 90.0]	
Age Category			
<50	19 (0.6%)	14 (3.2%)	<0.001
>79	749 (22.6%)	87 (19.7%)	
50-59	106 (3.2%)	45 (10.2%)	
60-69	856 (25.8%)	115 (26.0%)	
70-79	1585 (47.8%)	181 (41.0%)	
Sex			
Female	800 (24.1%)	177 (40.0%)	<0.001
Male	2515 (75.9%)	265 (60.0%)	
Ethnicity			
Hispanic or Latino	114 (3.4%)	17 (3.8%)	0.77
Non-Hispanic or -Latino	3190 (96.2%)	424 (95.9%)	
Missing	11 (0.3%)	1 (0.2%)	
Race			
American Indian or Alaskan Native	8 (0.2%)	1 (0.2%)	<0.001
Asian	68 (2.1%)	10 (2.3%)	
Black or African American	221 (6.7%)	62 (14.0%)	
More than 1 race	5 (0.2%)	1 (0.2%)	

Native Hawaiian or other Pacific Islander	2 (0.1%)	1 (0.2%)	
White	2784 (84.0%)	314 (71.0%)	
Unknown/Other	227 (6.8%)	53 (12.0%)	
Transfer			
Hospital	51 (1.5%)	215 (48.6%)	<0.001
Rehab Unit	2 (0.1%)	1 (0.2%)	
No	3262 (98.4%)	226 (51.1%)	
Primary Insurer			
Commercial	792 (23.9%)	111 (25.1%)	<0.001
Medicaid	70 (2.1%)	31 (7.0%)	
Medicare	1754 (52.9%)	208 (47.1%)	
Military/VA	131 (4.0%)	13 (2.9%)	
Non-US Insurance	191 (5.8%)	10 (2.3%)	
Self-Pay	14 (0.4%)	12 (2.7%)	
Missing	363 (11.0%)	57 (12.9%)	
Living Status			
Home	3289 (99.2%)	435 (98.4%)	0.23
Homeless	3 (0.1%)	1 (0.2%)	
Nursing home	23 (0.7%)	6 (1.4%)	
Functional Status			
Assisted care	53 (1.6%)	22 (5.0%)	<0.001
Bed bound	5 (0.2%)	1 (0.2%)	
Full	2042 (61.6%)	246 (55.7%)	
Light work	831 (25.1%)	117 (26.5%)	
Self-care	382 (11.5%)	55 (12.4%)	
Missing	2 (0.1%)	1 (0.2%)	

Cerebrovascular Disease History			
No	2946 (88.9%)	376 (85.1%)	0.02
Yes	369 (11.1%)	66 (14.9%)	
Coronary Artery Disease History			
No	2366 (71.4%)	298 (67.4%)	0.11
Yes	949 (28.6%)	143 (32.4%)	
Missing	0 (0%)	1 (0.2%)	
Congestive Heart Failure History			
No	2806 (84.6%)	358 (81.0%)	0.06
Yes	509 (15.4%)	84 (19.0%)	
Chronic Obstructive Pulmonary Disorder History			
No	1952 (58.9%)	247 (55.9%)	0.25
Yes	1363 (41.1%)	195 (44.1%)	
Diabetes History			
No	2692 (81.2%)	356 (80.5%)	0.79
Yes	623 (18.8%)	86 (19.5%)	
Dialysis Status			
No	3256 (98.2%)	424 (95.9%)	0.003
Yes	59 (1.8%)	18 (4.1%)	
Hypertension History			
No	330 (10.0%)	34 (7.7%)	0.16
Yes	2978 (89.8%)	405 (91.6%)	
Missing	7 (0.2%)	3 (0.7%)	
Smoking Status			

No	359 (10.8%)	63 (14.3%)	0.04
Yes	2956 (89.2%)	378 (85.5%)	
Missing	0 (0%)	1 (0.2%)	
History of Coronary Artery Bypass Surgery			
No	2721 (82.1%)	367 (83.0%)	0.69
Yes	592 (17.9%)	75 (17.0%)	
Missing	2 (0.1%)	0 (0%)	
History of Percutaneous Coronary Intervention			
No	2548 (76.9%)	352 (79.6%)	0.19
Yes	764 (23.0%)	89 (20.1%)	
Missing	3 (0.1%)	1 (0.2%)	
Aneurysm Repair History			
No	2549 (76.9%)	292 (66.1%)	<0.001
Yes	766 (23.1%)	150 (33.9%)	
Stress Test			
No	1717 (51.8%)	341 (77.1%)	<0.001
Yes	1595 (48.1%)	101 (22.9%)	
Missing	3 (0.1%)	0 (0%)	
Creatinine			
Mean (SD)	1.17 (0.612)	1.16 (0.686)	0.76
Median [Min, Max]	1.07 [0, 14.4]	1.00 [0.340, 7.50]	
Missing	74 (2.2%)	16 (3.6%)	
Chronic Kidney Disease Staging			

Normal or increased GFR	619 (18.7%)	111 (25.1%)	<0.001
Mildly decreased GFR	1548 (46.7%)	172 (38.9%)	
Mildly to severely decreased GFR	971 (29.3%)	123 (27.8%)	
Severely decreased GFR	89 (2.7%)	13 (2.9%)	
End-stage renal disease	14 (0.4%)	7 (1.6%)	
Missing	74 (2.2%)	16 (3.6%)	
Discharge ASA			
No	456 (13.8%)	53 (12.0%)	0.49
Yes	2772 (83.6%)	363 (82.1%)	
Missing	87 (2.6%)	26 (5.9%)	
Discharge P2Y12 Antagonist			
No	1382 (41.7%)	217 (49.1%)	<0.001
Yes	1845 (55.7%)	199 (45.0%)	
Missing	88 (2.7%)	26 (5.9%)	
Discharge Statin			
No	536 (16.2%)	62 (14.0%)	0.42
Yes	2692 (81.2%)	354 (80.1%)	
Missing	87 (2.6%)	26 (5.9%)	

Table S3. Comparison of Operative & Anatomical Factors

Variable	Asymptomatic (N=3315)	Symptomatic (N=442)	P-value
Prior Aortic Surgery			
Both	91 (2.7%)	16 (3.6%)	<0.001
Endo	407 (12.3%)	95 (21.5%)	
None	2563 (77.3%)	281 (63.6%)	
Open	254 (7.7%)	50 (11.3%)	
Pathology			
Aneurysm	3176 (95.8%)	358 (81.0%)	<0.001
Aneurysm from dissection	79 (2.4%)	30 (6.8%)	
Dissection	38 (1.1%)	37 (8.4%)	
PAU/IMH	22 (0.7%)	17 (3.8%)	
Maximum Aortic Diameter			
Mean (SD)	61.2 (10.5)	65.9 (18.2)	<0.001
Median [Min, Max]	60.0 [5.00, 130]	63.0 [5.50, 190]	
Missing	17 (0.5%)	7 (1.6%)	
Urgency			
Elective	3281 (99.0%)	246 (55.7%)	<0.001
Emergent	2 (0.1%)	32 (7.2%)	
Urgent	32 (1.0%)	164 (37.1%)	
Aneurysm Type			
Anastomotic	37 (1.1%)	8 (1.8%)	<0.001
Degenerative, fusiform	2753 (83.0%)	297 (67.2%)	
Degenerative, saccular	290 (8.7%)	38 (8.6%)	

Intercostal or visceral patch	14 (0.4%)	1 (0.2%)	
Prior trauma	0 (0%)	2 (0.5%)	
Missing	221 (6.7%)	96 (21.7%)	
Dissection Type			
Acute, <= 30 days	5 (0.2%)	34 (7.7%)	<0.001
Chronic, >30 days	112 (3.4%)	33 (7.5%)	
Missing	3198 (96.5%)	375 (84.8%)	
Genetic History			
Ehlers-Danlos	1 (0.0%)	1 (0.2%)	0.53
Loeys-Dietz	1 (0.0%)	0 (0%)	
Marfans	12 (0.4%)	2 (0.5%)	
Non-specific	86 (2.6%)	10 (2.3%)	
None	3212 (96.9%)	429 (97.1%)	
Missing	3 (0.1%)	0 (0%)	
Proximal Zone of Disease			
Mean (SD)	6.74 (1.62)	5.56 (1.97)	<0.001
Median [Min, Max]	7.00 [2.00, 9.00]	5.00 [2.00, 9.00]	
Distal Zone of Disease			
10B	716 (21.6%)	91 (20.6%)	<0.001
10L	129 (3.9%)	14 (3.2%)	
10R	193 (5.8%)	19 (4.3%)	
11B	64 (1.9%)	10 (2.3%)	
11L	37 (1.1%)	8 (1.8%)	
11R	39 (1.2%)	11 (2.5%)	
4	1 (0.0%)	1 (0.2%)	

5	21 (0.6%)	4 (0.9%)	
6	24 (0.7%)	12 (2.7%)	
7	25 (0.8%)	18 (4.1%)	
8	158 (4.8%)	30 (6.8%)	
9	1908 (57.6%)	224 (50.7%)	
Type of TAAA			
Juxtarenal AAA	1347 (40.6%)	94 (21.3%)	<0.001
Type 1 TAAA	9 (0.3%)	4 (0.9%)	
Type 2 TAAA	137 (4.1%)	69 (15.6%)	
Type 3 TAAA	534 (16.1%)	118 (26.7%)	
Type 4 TAAA	1049 (31.6%)	110 (24.9%)	
Type 5 TAAA	51 (1.5%)	15 (3.4%)	
Missing	188 (5.7%)	32 (7.2%)	
Anesthesia			
General	3279 (98.9%)	434 (98.2%)	0.24
Local	21 (0.6%)	6 (1.4%)	
Regional	15 (0.5%)	2 (0.5%)	
Iodinated Contrast			
Mean (SD)	127 (70.4)	128 (79.9)	0.67
Median [Min, Max]	115 [0, 677]	114 [0, 501]	
Missing	74 (2.2%)	11 (2.5%)	
Estimated Blood Loss			
Mean (SD)	417 (695)	405 (443)	0.64
Median [Min, Max]	250 [0, 25000]	250 [0, 3000]	
Missing	34 (1.0%)	7 (1.6%)	
Fluoroscopy Time			

Mean (SD)	73.9 (38.8)	71.6 (44.1)	0.32
Median [Min, Max]	66.0 [1.00, 320]	64.0 [6.80, 285]	
Missing	169 (5.1%)	26 (5.9%)	
Packed Red Blood Cells given in OR or Preop			
Mean (SD)	0.594 (3.92)	1.03 (1.97)	<0.001
Median [Min, Max]	0 [0, 200]	0 [0, 16.0]	
Missing	3 (0.1%)	2 (0.5%)	
Total Procedure Time			
Mean (SD)	252 (111)	267 (129)	0.02
Median [Min, Max]	231 [25.0, 911]	239 [52.0, 852]	
Missing	3 (0.1%)	1 (0.2%)	
Intravascular Ultrasound (IVUS) or Transesophageal Echo (TEE)			
Both	30 (0.9%)	7 (1.6%)	<0.001
IVUS	515 (15.5%)	130 (29.4%)	
No	2720 (82.1%)	293 (66.3%)	
TEE	34 (1.0%)	12 (2.7%)	
Missing	16 (0.5%)	0 (0%)	
Left or Right Access			
Open	1064 (32.1%)	148 (33.5%)	0.3
Percutaneous	1972 (59.5%)	243 (55.0%)	
Missing	279 (8.4%)	51 (11.5%)	
Arm/Neck Access			
No	2567 (77.4%)	282 (63.8%)	<0.001
Yes	748 (22.6%)	160 (36.2%)	

Number of Aortic Devices			
Mean (SD)	2.22 (0.898)	2.56 (1.24)	<0.001
Median [Min, Max]	2.00 [1.00, 6.00]	2.00 [1.00, 6.00]	
Custom/Modified Devices			
No	803 (24.2%)	100 (22.6%)	0.5
Yes	2512 (75.8%)	342 (77.4%)	
Graft Type			
Custom	1586 (47.8%)	93 (21.0%)	<0.001
Physician modified	839 (25.3%)	218 (49.3%)	
Standard	890 (26.8%)	131 (29.6%)	
Right Iliac Endpoint			
Common	1972 (59.5%)	183 (41.4%)	0.13
External, Unintended	20 (0.6%)	4 (0.9%)	
External, Intended	241 (7.3%)	33 (7.5%)	
None	24 (0.7%)	2 (0.5%)	
Missing	1058 (31.9%)	220 (49.8%)	
Left Iliac Endpoint			
Common	1985 (59.9%)	179 (40.5%)	0.06
External, Unintended	13 (0.4%)	4 (0.9%)	
External, Intended	197 (5.9%)	24 (5.4%)	
None	24 (0.7%)	1 (0.2%)	
Missing	1096 (33.1%)	234 (52.9%)	
Staged Branch Treatment			
No	3131 (94.4%)	404 (91.4%)	0.01
Yes	178 (5.4%)	38 (8.6%)	

Missing	6 (0.2%)	0 (0%)	
Left Subclavian Proximal Branch Treatment			
No	3251 (98.1%)	396 (89.6%)	<0.001
Yes	64 (1.9%)	46 (10.4%)	
Celiac Proximal Branch Treatment			
No	1453 (43.8%)	76 (17.2%)	<0.001
Yes	1862 (56.2%)	366 (82.8%)	
SMA Proximal Branch Treatment			
No	416 (12.5%)	26 (5.9%)	<0.001
Yes	2899 (87.5%)	416 (94.1%)	
Right Renal Proximal Branch Treatment			
No	23 (0.7%)	18 (4.1%)	<0.001
Yes	3292 (99.3%)	424 (95.9%)	
Left Renal Proximal Branch Treatment			
No	23 (0.7%)	18 (4.1%)	<0.001
Yes	3292 (99.3%)	424 (95.9%)	
Time to Extubation			
<12 hrs	151 (4.6%)	31 (7.0%)	<0.001
>24 hrs	75 (2.3%)	29 (6.6%)	
12-24 hrs	81 (2.4%)	23 (5.2%)	
In OR	2964 (89.4%)	348 (78.7%)	
Missing	44 (1.3%)	11 (2.5%)	
Spinal Drain Placement			

No	2743 (82.7%)	296 (67.0%)	<0.001
Yes	571 (17.2%)	146 (33.0%)	
Missing	1 (0.0%)	0 (0%)	
Treatment Left Renal			
None	307 (9.3%)	39 (8.8%)	<0.001
Occluded/Covered	101 (3.0%)	30 (6.8%)	
Scallop/Fen/Branch/ Chimney	2876 (86.8%)	354 (80.1%)	
Missing	31 (0.9%)	19 (4.3%)	
Treatment Right Renal			
None	340 (10.3%)	64 (14.5%)	<0.001
Occluded/Covered	97 (2.9%)	28 (6.3%)	
Scallop/Fen/Branch/ Chimney	2758 (83.2%)	319 (72.2%)	
Missing	120 (3.6%)	31 (7.0%)	
Treatment SMA			
None	241 (7.3%)	35 (7.9%)	0.88
Occluded/Covered	4 (0.1%)	1 (0.2%)	
Scallop/Fen/Branch/ Chimney	2647 (79.8%)	379 (85.7%)	
Missing	423 (12.8%)	27 (6.1%)	
Treatment Celiac			
None	364 (11.0%)	58 (13.1%)	0.04
Occluded/Covered	92 (2.8%)	28 (6.3%)	
Scallop/Fen/Branch/ Chimney	1400 (42.2%)	280 (63.3%)	
Missing	1459 (44.0%)	76 (17.2%)	
Treatment Left Subclavian			

None	15 (0.5%)	14 (3.2%)	0.22
Occluded/Covered	6 (0.2%)	12 (2.7%)	
Scallop/Fen/Branch/ Chimney	10 (0.3%)	6 (1.4%)	
Missing	3284 (99.1%)	410 (92.8%)	
Number of Treated Branches			
1	352 (10.6%)	63 (14.3%)	<0.001
2	732 (22.1%)	82 (18.6%)	
3	1059 (31.9%)	83 (18.8%)	
4	1172 (35.4%)	214 (48.4%)	
Number of Treated Renals			
0	439 (13.2%)	88 (19.9%)	<0.001
1	118 (3.6%)	35 (7.9%)	
2	2758 (83.2%)	319 (72.2%)	
Number of Occluded Renals			
Yes	101 (3.0%)	30 (6.8%)	<0.001
No	3214 (97.0%)	412 (93.2%)	
SMA Proximal Branch Occluded			
Yes	4 (0.1%)	1 (0.2%)	1
No	3311 (99.9%)	441 (99.8%)	
Celiac Proximal Branch Occluded			
Yes	92 (2.8%)	28 (6.3%)	<0.001
No	3223 (97.2%)	414 (93.7%)	

Table S4. Comparison of Procedure Outcomes

Variable	Asymptomatic (N=3315)	Symptomatic (N=442)	P-value
Length of stay in days between admission date and discharge date			
Mean (SD)	6.17 (19.5)	12.1 (26.4)	<0.001
Median [Min, Max]	3.00 [0, 374]	7.00 [1, 376]	
Missing	1 (0.0%)	0 (0%)	
Length of stay in days between surgery date and discharge date			
Mean (SD)	5.37 (16.8)	7.93 (8.44)	<0.001
Median [Min, Max]	3.00 [0, 372]	6.00 [0, 80]	
Missing	1 (0.0%)	0 (0%)	
Deployment Technical Success			
No	108 (3.3%)	17 (3.8%)	0.53
Yes	3035 (91.6%)	389 (88.0%)	
Missing	172 (5.2%)	36 (8.1%)	
Conversion to Open			
No	3301 (99.6%)	439 (99.3%)	0.71
Yes	14 (0.4%)	3 (0.7%)	
Endoleak at Completion of Procedure			
No	1073 (32.4%)	127 (28.7%)	1
Yes	2159 (65.1%)	257 (58.1%)	
Missing	83 (2.5%)	58 (13.1%)	
ICU Stay			
Mean (SD)	2.14 (4.19)	4.19 (5.49)	<0.001

Median [Min, Max]	1 [0, 85]	3 [0, 49]	
Missing	6 (0.2%)	2 (0.5%)	
Transfusion # Units PRBC			
Mean (SD)	1.15 (3.69)	2.13 (4.07)	<0.001
Median [Min, Max]	0 [0, 77]	0 [0, 38]	
Missing	2 (0.1%)	1 (0.2%)	
Vasopressors Post-op			
No	2752 (83.0%)	304 (68.8%)	<0.001
Yes	560 (16.9%)	138 (31.2%)	
Missing	3 (0.1%)	0 (0%)	
Highest Creatinine			
Mean (SD)	1.46 (1.14)	1.80 (1.75)	<0.001
Median [Min, Max]	1.18 [0.01,15.4]	1.19 [0.45,11.8]	
Missing	23 (0.7%)	4 (0.9%)	
Post-op GFR			
Mean (SD)	61.3 (24.8)	56.9 (28.1)	0.002
Median [Min, Max]	62.1 [3.02, 342]	58.0 [3.82, 111]	
Missing	23 (0.7%)	4 (0.9%)	
Post-op Chronic Kidney Disease Staging			
Normal or increased GFR	536 (16.2%)	69 (15.6%)	<0.001
Mildly decreased GFR	1253 (37.8%)	144 (32.6%)	
Mildly to severely decreased GFR	1139 (34.4%)	145 (32.8%)	
Severely decreased GFR	243 (7.3%)	37 (8.4%)	
End-stage renal disease	121 (3.7%)	43 (9.7%)	
Missing	23 (0.7%)	4 (0.9%)	

Any Complications Post-op			
No	2676 (80.7%)	309 (69.9%)	<0.001
Yes	638 (19.2%)	133 (30.1%)	
Missing	1 (0.0%)	0 (0%)	
Puncture Site Hematoma or Access Site Occlusion			
No	1258 (37.9%)	158 (35.7%)	0.09
Yes	57 (1.7%)	13 (2.9%)	
Missing	2000 (60.3%)	271 (61.3%)	
Post-op Abnormal Heart Disease or Myocardial Infarction or Dysrhythmia			
No	2995 (90.3%)	387 (87.6%)	0.08
Yes	319 (9.6%)	55 (12.4%)	
Missing	1 (0.0%)	0 (0%)	
Post-op Cerebrovascular Stroke			
No	3282 (99.0%)	427 (96.6%)	<0.001
Yes	32 (1.0%)	15 (3.4%)	
Missing	1 (0.0%)	0 (0%)	
Post-op Respiratory			
No	3171 (95.7%)	396 (89.6%)	<0.001
Yes	143 (4.3%)	46 (10.4%)	
Missing	1 (0.0%)	0 (0%)	
Post-op Dialysis			
No	3203 (96.6%)	405 (91.6%)	<0.001
Yes	64 (1.9%)	22 (5.0%)	
Missing	48 (1.4%)	15 (3.4%)	

Arm Ischemia/Emboli			
No	3303 (99.6%)	440 (99.5%)	1
Yes	11 (0.3%)	2 (0.5%)	
Missing	1 (0.0%)	0 (0%)	
Leg Ischemia/Emboli			
No	3246 (97.9%)	423 (95.7%)	0.01
Yes	68 (2.1%)	19 (4.3%)	
Missing	1 (0.0%)	0 (0%)	
Leg Compartment Syndrome			
No	3279 (98.9%)	438 (99.1%)	0.96
Yes	35 (1.1%)	4 (0.9%)	
Missing	1 (0.0%)	0 (0%)	
Post-op Intestinal Ischemia			
No	3252 (98.1%)	431 (97.5%)	0.48
Yes	62 (1.9%)	11 (2.5%)	
Missing	1 (0.0%)	0 (0%)	
Post-op Renal Ischemia			
No	3217 (97.0%)	426 (96.4%)	0.51
Yes	97 (2.9%)	16 (3.6%)	
Missing	1 (0.0%)	0 (0%)	
Post-op Spinal Ischemia			
No	3212 (96.9%)	405 (91.6%)	<0.001
Yes	102 (3.1%)	37 (8.4%)	
Missing	1 (0.0%)	0 (0%)	
Reintervention			
No	3106 (93.7%)	389 (88.0%)	<0.001

Yes	207 (6.2%)	53 (12.0%)	
Missing	2 (0.1%)	0 (0%)	
Discharge Status			
Dead	81 (2.4%)	25 (5.7%)	<0.001
Home	2837 (85.6%)	309 (69.9%)	
Homeless	1 (0.0%)	1 (0.2%)	
Nursing Home	100 (3.0%)	24 (5.4%)	
Other Hospital	29 (0.9%)	16 (3.6%)	
Rehab Unit	264 (8.0%)	67 (15.2%)	
Missing	3 (0.1%)	0 (0%)	
Post-Treatment of All Branches			
No	2842 (85.7%)	319 (72.2%)	<0.001
Yes	471 (14.2%)	122 (27.6%)	
Missing	2 (0.1%)	1 (0.2%)	