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Multi-branched Endovascular Aortic Aneurysm Repair in Patients With and Without Chronic Aortic Dissections

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Abstract

Objective: To compare multi-branched endovascular repair (MBEVAR) of post-dissection thoracoabdominal aneurysms (TAAA) and para-renal aortic aneurysms (PRAA) with MBEVAR of degenerative TAAA and PRAA, and assess the role played by the preoperative correction of potential complicating factors such as true lumen compression and false lumen origin of vital branches using adjunctive maneuvers.

Methods: From 7/2005 to 7/2017, 162 patients underwent elective MBEVAR of TAAA and PRAA. Data on demographics, procedural details, and outcomes were collected prospectively.

Results: The mean age was 73±8 years and 119/162 (74%) were men. 19/162 (12%) had prior aortic dissections. Patients with dissections were younger (65±11 vs 74±7 years, p=.002), and were less likely to have smoked (13/19[68%] vs 135/143[94%], p=.002) or have peripheral artery disease (0/19[0%] vs 35/143[24%], p=.01) compared to those without dissections. Patients with prior dissections were more likely to have Crawford type II (10/19[53%] v. 22/143 [15%], p=.001) and type III (6/19[32%] v. 16/143[11%], p=.03) TAAA, and were more likely to require at least one pre-MBEVAR adjunctive procedure (14/19[74%] vs. 55/143[38%], p=.006) compared to those without dissection. There was no difference in perioperative death, stroke, or paraplegia rates between the two groups. Median follow-up (IQR) was 2.4 years (0.8 – 4.7) and did not differ significantly between the two groups. There were no significant differences in branch vessel occlusion, endoleak rate, or aneurysm-related death between the two groups.

Conclusions: Patient with chronic type B aortic dissection are more likely to have extensive aneurysms, and more likely to require adjunctive procedures to provide the appropriate anatomic

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Declaration of Conflicting Interests
Jade S. Hiramoto and Timothy A. M. Chuter receive research support and royalties for patents from Cook Medical, Incorporated. The other authors have nothing to disclose.

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substrate for MBEVAR, but this does not appear to affect the conduct of MBEVAR or its outcomes.

Table of Contents Summary

Retrospective analysis of prospectively collected data of 162 elective multi-branched endovascular repairs (MBEVARs), performed for complex aortic aneurysms, revealed that 19 patients with prior aortic dissections were more likely to have extensive aneurysms and require adjunctive procedures before MBEVAR, but this did not to affect clinical outcomes.

Keywords

branched stent graft; dissection; aortic aneurysm

Introduction

Untreated dissection eventually causes aneurysms in approximately 20–50% of cases[1–4]. Conventional (two-cavity) open repair of the resulting aneurysm (usually Crawford type I or II) is often complicated by death, paraplegia or renal failure[5–7], and conventional (unbranched) endovascular repair is often ineffective[4,8]. Hybrid operations – involving endovascular repair of the thoracic aorta followed by open repair of the visceral portion[9], or open debranching of the visceral portion followed by endovascular repair of the entire aorta[10] – produce little, if any, reduction in the morbidity and mortality rates experienced by high-risk patients.

A more radical solution, in the form of a multi-branched endovascular repair (MBEVAR), has shown promise in experienced hands[4,11–13]. These branches may be fenestration-based or cuff-based. At this stage, the numbers are small. In addition, some reports mix arch repair with thoraco-abdominal repair.

MBEVAR of thoracoabdominal aortic aneurysms (TAAA) was first performed at UCSF using a homemade stent graft in 2000, using a manufactured stent graft in 2005[14], and for aortic dissection in 2006. Yet the next 5 years yielded only 5 more cases of dissection-related TAAA repair. During that time, the rate-limiting step was not a shortage of cases, but a high prevalence of perceived anatomic obstacles to endovascular intervention, such as true lumen compression, branch arteries off of the false lumen, and dissection of aortic branches. The more widespread application of MBEVAR in cases of post-dissection TAAA came through the gradual realization that we could eliminate many of the associated anatomic obstacles prior to definitive repair by employing a number of relatively simple adjunctive maneuvers.

This study compares MBEVAR of post-dissection versus degenerative TAAA and pararenal aortic aneurysms (PRAA), using an exclusively cuff-based approach to the repair. We test the assumption that adjunctive procedures can provide an appropriate anatomic substrate for MBEVAR regardless of the underlying aortic pathology.

Methods

Clinical Trial

This single-center, prospective clinical trial was conducted under an Investigational Device Exemption by the Food and Drug Administration and approved by the Committee on Human Research at the University of California, San Francisco. Starting in July 2005, we used a modular multi-branched aortic stent graft (Cook Australia, Brisbane, Australia) for endovascular repair of TAAA and PRAA. All patients provided informed consent.

During MBEVAR, arterial access was obtained through surgical exposure of the femoral and brachial arteries. After the modular aortic components were placed through the femoral arteries, the sheaths were removed and the femoral artery access sites were repaired in order to restore perfusion to the pelvis and lower extremities. After insertion of a brachiofemoral wire, covered stents were inserted through the brachial artery to connect the cuffs within the tapered portion of the stent-graft to the visceral and renal arteries, as previously described[14].

All patients underwent pre-operative placement of a lumbar catheter to drain cerebrospinal fluid (CSF). CSF was drained at a rate of 10 ml/hour intraoperatively, and an additional 10 ml of CSF was drained after insertion of the final branch of the MBEVAR. CSF drainage was continued at 10 ml/hour for the first 24 hours after surgery, and subsequent management of the CSF drain was dependent on the patient's neurologic status.

Patient demographics, comorbid conditions, previous surgical history, imaging results, procedural details, clinical outcomes, and adverse events were recorded prospectively. Aneurysm extent was based on pre-operative computed tomographic angiography (CTA) and the Crawford classification of TAAA. Postoperative follow-up for all patients included a clinical evaluation and CTA before discharge and at 1 month, 6 months, 12 months, and then yearly

Adjunctive Procedures

Many of the patients in this study required separate preparatory operations and interventions to eliminate anatomic obstacles to subsequent MBEVAR. These adjunctive procedures were grouped and categorized according to the underlying anatomical problem. For example, patients who underwent pre-MBEVAR iliofemoral bypass, aortofemoral bypass, endoconduit placement, or iliac stenting for poor arterial access were defined as undergoing adjunctive procedures for "small or tortuous femoral/iliac artery access". Patients who underwent pre-MBEVAR visceral or renal artery angioplasty or stenting were defined as undergoing adjunctive procedures for "branch vessel stenosis". Patients who required pre-MBEVAR subclavian artery revascularization to extend the proximal attachment site were defined as having undergone an adjunctive procedure for "proximal extent of disease". Those patients who required iliofemoral bypass, common iliac artery transection with cross femoral bypass, external to internal iliac artery bypass, or bifurcated common iliac artery stent graft were defined as having undergone an adjunctive procedure for "distal extent of disease". Patients with true lumen compression who underwent aortic septum fenestration or aortic stent placement were defined as having undergone adjunctive procedures for "true lumen compression". Patients with visceral or renal arteries originating from different lumens of the visceral aorta were defined as undergoing adjunctive procedures (usually involving septal lysis) for “aortic compartmentalization”. Several patients in this study presented to us after already having undergone some form of open repair of the ascending aorta or aortic arch. These procedures that were performed *prior* to presentation to our center for treatment of a TAAA or PRAA were not included in this analysis.

Statistical Analysis

Statistical analysis was performed with Stata/SE 14 (StatCorp LP, CollegeStation, Tex). Measured values are reported as percentages or mean ± standard deviation. Mean values of continuous variables were compared using the student *t* test. The Fisher exact test was used to compare categorical variables. Kaplan-Meier analysis was performed for survival data and the log-rank test was used to compare survival data between groups. P-values ≤ 0.5 were considered statistically significant.

RESULTS:

From July 2005 through July 2017, 162 asymptomatic patients underwent MBEVAR to treat TAAA or PRAA. The mean age for the study group as a whole was 73±8 years and 119/162 (74%) were men (Table I). 19/162 (12%) had pre-existing aortic dissections. Of those patients with aortic dissections, 2/19 (11%) had type A dissections, 15/19 (79%) had type B dissections, and 2/19 (11%) had both types. The 2 patients with type A dissections had previously undergone open surgical treatment of the ascending aorta and subsequently presented to us with a TAAA. Based on the available imaging studies, it was not entirely clear if these were true degenerative aneurysms of the thoracoabdominal aorta or if the aneurysms were related to the prior type A dissection. The 2 patients with “both types” refers to a dissection of the entire thoracoabdominal aorta, including the ascending aorta and arch.

There was no difference in aneurysm diameter (mean: 66 mm ± 9) between those with and without dissection. Patients with dissections were younger (65±11 vs 74±7 years, p=.002), and were less likely to have smoked (13/19[68%] vs 135/143[94%], p=.002) or have peripheral artery disease (0/19[0%] vs 35/143[24%], p=.01) compared to those without dissections (Table I). Patients with prior dissections were more likely to have Crawford type II (10/19[53%] vs. 22/143 [15%], p=.001) and type III (6/19[32%] vs. 16/143[11%], p=.03) TAAA (Table I).

Patients with pre-existing dissections were more likely to require at least one pre-MBEVAR adjunctive procedure (14/19[74%] vs. 55/143[38%], p=.006) compared to those without dissections. The 14 patients with pre-existing dissections required a total of 25 pre-MBEVAR adjunctive procedures, while the 55 patients without dissections required a total of 64 pre-MBEVAR adjunctive procedures (Table II). Patients with pre-existing dissections were *more* likely to undergo adjunctive procedures for the treatment of the distal extent of disease (7/25[28%] v. 0/64[0%], p<.001), true lumen compression (3/25[12%] v. 0/64[0%], p=.02) and aortic compartmentalization (4/25[16%] v. 0/64[0%], p=.005) (Table II). On the other hand, patients with dissection were *less* likely to undergo adjunctive procedures for the treatment of small or tortuous iliac/femoral artery access (3/25[12%] v. 34/64[53%], p<.001) as well as the treatment of branch vessel stenosis (3/25[12%] v. 26/64[41%], p=.01).

Patients with pre-existing dissections were a very heterogeneous group. Most had anatomic distortions severe enough to warrant preoperative correction, but no two had exactly the same pattern of anatomic distortion or underwent exactly the same combination of adjunctive maneuvers. For example, in one case, bilateral common iliac artery dissection caused bilateral iliac aneurysms (large enough to preclude common iliac implantation) and external iliac artery tortuosity (severe enough to prevent transfemoral stent graft insertion). Right external-to-external and external-to-internal iliac artery bypass was performed pre-operatively to provide a route for stent graft insertion through the right common femoral artery (Figure 1) and bifurcated iliac stent graft implantation was performed intraoperatively to preserve flow to the pelvis through the left internal iliac artery.

One patient exhibited a common form of aortic compartmentalization in which the celiac trunk, SMA and right renal artery were perfused by the true lumen and left renal artery was perfused by the false lumen (Figure 2). Using a sort of endovascular Gigli saw—fashioned from a Bentson guidewire with the tip cut off and the central portion of the outer wrap stretched to space the coils—a long incision in the septum was created to relieve true lumen compression and provide access to all 4 branches. Unfortunately, the newly mobile flap of the inter-compartmental septum occluded the celiac and superior mesenteric arteries, necessitating the urgent implantation of long self-expanding stents to restore unimpeded flow. The proximal end of the superior mesenteric stent ended at the aortic wall, but the celiac stent had to extend well into the aortic lumen because that portion of the flap was longer (Figure 2). Before implanting the stent graft – and potentially pushing the intra-aortic segment of the superior mesenteric stent down, to the right, or to the left, any of which would make it inaccessible through the caudally-oriented cuff – we inflated a long balloon to make it stand up. None of these problems required major surgical correction, and none had much effect on the performance of the definitive repair.

Alternative methods of septal lysis involved balloon dilation of pre-existing fenestrations within the visceral segment, or ultrasound-guided septal puncture, followed by balloon dilation of one or more newly created fenestrations. Although the true lumen compression (inner-to-outer dimension <20 mm) was present in most (9/19) patients who had type B dissection in the absence of prior thoracic aortic intervention or operation, less than half (4/9) required septal lysis, mainly to treat the associated aortic compartmentalization.

There were no significant differences between the two groups in the various indices of operative complexity (Table III), in short and long-term complication rates (Table IV), or in freedom from aneurysm-related death (Figure 3). Although neither case of aneurysm rupture in the dissection group was based on autopsy findings, we attributed both to aneurysm rupture due to direct endoleak which was seen on the first postoperative CT and persistent despite attempted catheter-based treatment. One had a type 1B endoleak through the false lumen of a dissected SMA. The other had a type 1B endoleak around the distal end of an inadequately sealed renal branch.

Discussion

Untreated dissection of the descending thoracic aorta (type B) is often complicated by false lumen dilatation, starting at the arch and progressing distally[1–4]. By the time the resulting aneurysm is large enough to warrant repair, the opportunity for straight-forward endovascular implantation of an aorto-aortic stent graft has been lost. In most cases of post-dissection aneurysm, the dilated false lumen is separated from the compressed true lumen by a rigid fibrotic interluminal septum and is fed by multiple paravisceral fenestrations. Implanting the distal end of a stent graft into the true lumen above the visceral branches does nothing to interrupt the path of retrograde flow through the false lumen to the aneurysm. Under these circumstances, the only viable targets for hemostatic distal implantation are the branch arteries themselves. As in all forms of total endovascular repair, the branching pattern of the stent graft has to match the branching pattern of the dissected aorta.

Several groups have reported successful repair of post-dissection TAAA and PRAA using modular techniques that preserve aortic integrity and branch vessel perfusion during the in-situ assembly of complex multi-branched stent grafts[4,11–13]. This modular approach has two main variants: fenestration-based and cuff-based, depending on the type of branch attachment. Most groups show a preference for fenestration-based branches. In our experience, the compressed true lumen will often become less slot-like and a lot more circular as stent graft components are added to fill the space. Others have observed that despite initially narrow lumen dimension, stent grafts expand over time to significantly increase the true lumen diameter after implantation[12,15]. Moreover, the trunk of the mulit-branched stent graft can be designed to be as narrow as 14 mm without depriving the stent graft of cuff attachment sites.

A high prevalence of anatomic obstacles such as true lumen compression and false lumen branch origination ensure that few post-dissection TAAA reach the stage of MBEVAR without some kind of adjunctive procedure[4]. Although the goal of adjunctive intervention is to standardize the arterial anatomy as much as possible, very few post-dissection aneurysms have the anatomic substrate for a standard off-the-shelf stent graft. In this series, all the stent grafts used to treat post-dissection aneurysms were custom-made.

The comparison of dissection-related versus degenerative TAAA shows that most are equally amenable to MBEVAR. But we have learned to beware certain features of the post-dissection aneurysm such as dissection of a target artery that extends to the orifice of a vital branch. One should always try to preserve the subclavian and internal iliac arteries, which both feed collateral pathways to the spine. It is sometimes impossible to preserve all the branches of a dissected superior mesenteric or renal artery. One, and possibly both, of the two aneurysm related deaths in the post-dissection group resulted from failure to prevent retrograde flow through the false lumen of a target artery. Although it may appear simple to block the false lumen using plugs and coils, flow somehow finds its way back to the aorta. And the implantation site does not have to be dissected to be unsuitable. As we found in some of the degenerative aneurysm cases, a moderately dilated proximal implantation site can be expected to dilate further, undermining the repair, especially when proximal extension would encroach on the aortic arch and especially when the patient has a connective tissue disorder. We do not always know whether or not a patient has an underlying aortopathy, but we prefer to avoid endovascular repair of TAAA under these circumstances and in young patients, unless the arch has been dealt with by conventional surgical means.

Limitations

Like most of the published series on the endovascular treatment of post-dissection TAAA[4,11–13], the current study suffers from low event rates, small numbers of dissection cases and short follow-up. The other main short coming of this paper is the lack of information on the patients who were refused MBEVAR. In addition, since we are a tertiary referral center, the majority of our patients had already been locally triaged and only represent a subset of all patients with post-dissection TAAA. Without these data, we cannot really comment on the selection criteria, the general applicability of the technique and the expanding role adjunctive maneuvers may play in preparing post-dissection TAAA and PRAA for MBEVAR. All we can say is that this technique remains a work-in-progress.

Conclusion

There appears to be little difference in the safety and efficacy of MBEVAR between post-dissection and degenerative TAAA and PRAA. Adjunctive maneuvers appear to be capable of leveling the playing field by eliminating anatomic obstacles to MBEVAR, many of which occur only in the presence of chronic dissection.

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Article Highlights:

Type of Research: Retrospective analysis of prospectively collected data

Key Findings:Analysis of 162 elective multi-branched endovascular repairs (MBEVARs), performed for complex aortic aneurysms, revealed that 19 patients with prior aortic dissections (AD) were more likely to have extensiveaneurysms and require at least one adjunctive procedure (14/19 [74%] vs. 55/143 [38%], p=.006) prior to MBEVAR compared to patients without AD. Branch vessel occlusion, endoleak rate, or aneurysm-related death was similar with or without AD at a median of 2.4 years.

Take Home Message: Patients with chronic AD are more likely to require adjunctive procedures to provide the appropriate anatomic substrate for MBEVAR, but this does not appear to affect clinical outcomes.

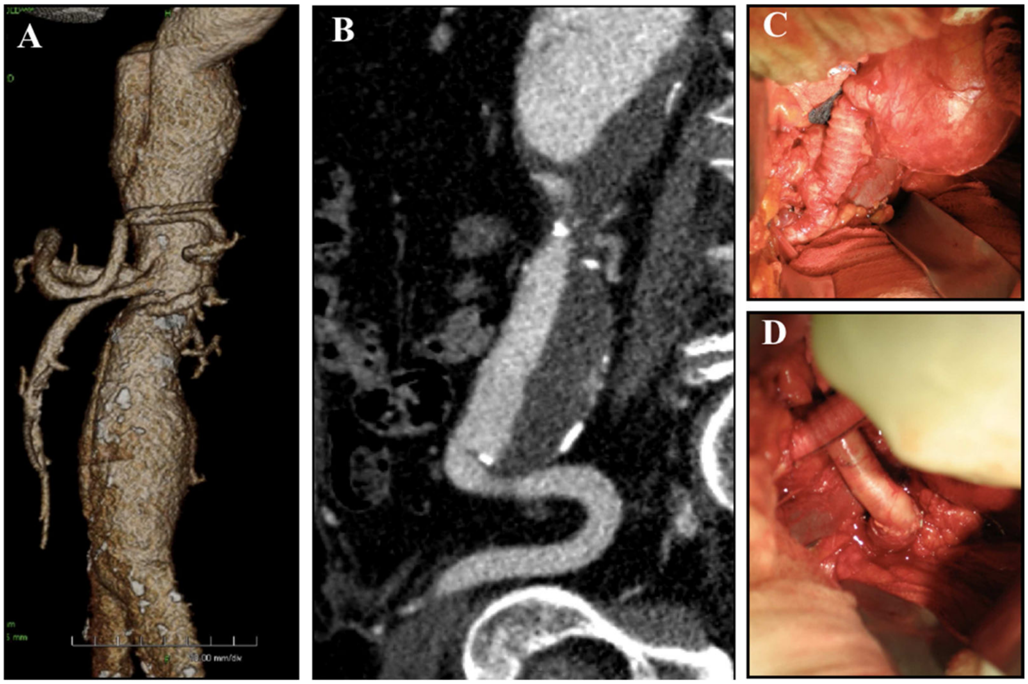

Figure 1:

Challenging anatomy posed by a chronic type B dissection extending down to the bilateral common iliac arteries leading to aneurysmal common iliac and tortuous external iliac arteries. (A) 3D reconstruction of pre-operative CTA demonstrating the visceral branches and adjacent inter-luminal septum. (B) Pre-operative sagittal CTA imaging demonstrating one of two large common iliac aneurysms and the resulting external iliac artery tortuosity. (C) Intraoperative photograph showing a short Dacron graft bypass from an end-to-end anastomosis on the stump of the external iliac artery to an end-to-side anastomosis on the distal external iliac artery. (D) Intraoperative photography, showing the proximal external iliac artery serving as a retrograde bypass to the internal iliac artery.

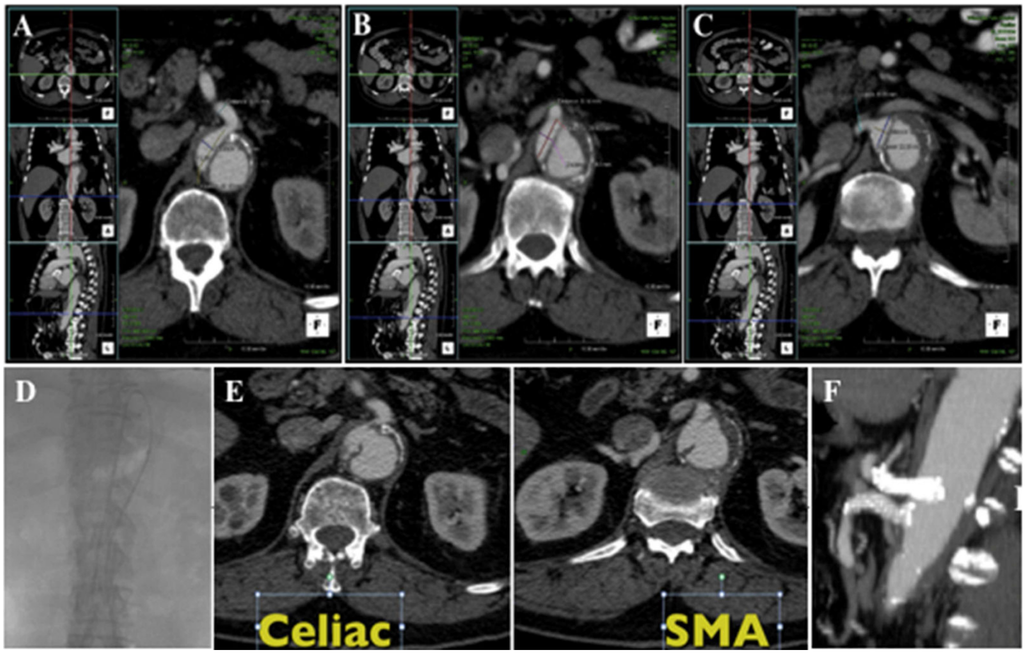

Figure 2:

(A) Preoperative CTA showing the origin of the celiac artery from the end of a narrowed true lumen. (B) Preoperative CTA, showing the origin of the superior mesenteric artery from the end of the narrow true lumen anterior and to the right of the much larger false lumen. (C) Preoperative CTA, showing the origin of the left renal arising from a slightly wider true lumen. (D) Intraoperative fluoroscopy, showing the Endovascular Gigli in action cutting the inter-luminal septum. (E) Postoperative CTA, showing a remnant of the inter-luminal septum partially occluding both the celiac and superior mesenteric arteries. (F) Postoperative CTA, stents holding both the celiac and superior mesenteric arteries open.

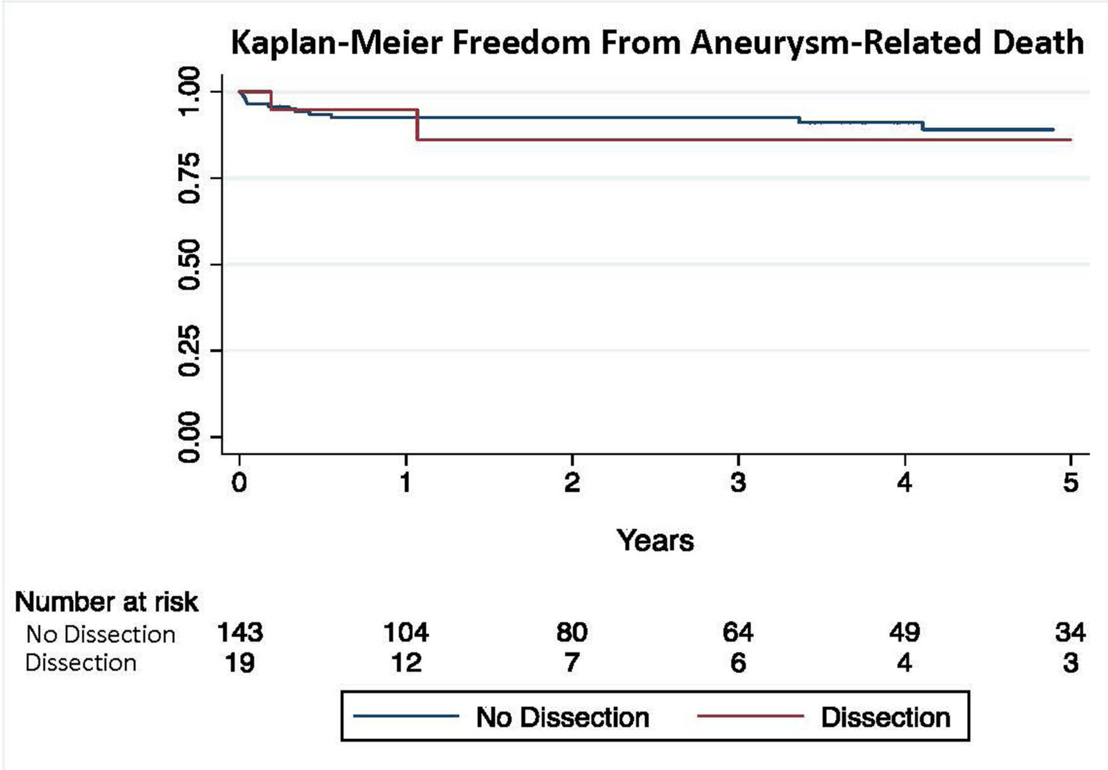

Figure 3:
Kaplan Meier curve depicting freedom from aneurysm-related death following MBEVAR.

Table I:

Summary of patient demographics.

	All (n = 162)	Dissection (n=19)	No Dissection (n=143)	P value
Mean Age ± SD, years	73 ± 8	65 ± 11	74 ± 7	**.002**
Male	119 (74%)	13 (68%)	106 (74%)	.59
Caucasian	136 (84%)	14 (74%)	122 (85%)	.19
History of Heart Disease *	88 (54%)	9 (47%)	79 (55%)	.63
History of Lung Disease †	87 (54%)	7 (37%)	80 (56%)	.14
History of Smoking	148 (91%)	13 (68%)	135 (94%)	**.002**
History of Stroke/Transient ischemic attack	33 (20%)	5 (26%)	28 (20%)	.55
History of Peripheral vascular disease ‡	35 (22%)	0 (0%)	35 (24%)	**.01**
History of Hypertension	154 (95%)	19 (100%)	135 (94%)	.60
History of Hemodialysis-dependent renal failure	5 (3%)	1 (5%)	4 (3%)	.47
History of Diabetes	20 (12%)	2(11%)	18 (13%)	1.00
Aneurysm Extent				
Type I	6 (4%)	1 (5%)	5 (4%)	.55
Type II	32 (20%)	10 (53%)	22 (15%)	**.001**
Type III	22 (14%)	6 (32%)	16 (11%)	**.03**
Type IV/Pararenal	89 (55%)	1 (5%)	88 (62%)	**<.001**
TypeV	13 (8%)	1 (5%)	12 (8%)	1.00
Mean Maximum aortic diameter ± SD, mm	66 ± 9	70 ± 12	66 ± 8	.22

* Includes history of angina, myocardial infarction, congestive heart failure, arrhythmia, coronary artery bypass graft, percutaneous coronary intervention, valve surgery, or pacemaker placement.

† Includes history of chronic bronchitis, emphysema, asthma, or use of home oxygen.

‡ Includes history of lower extremity claudication or lower extremity angioplasty, stent placement, bypass graft, or amputation.

Table II:

Summary of adjunctive procedures required prior to MBEVAR.

	Dissection (n=19)	No Dissection (n=143)	p-value
Patients requiring adjunctive procedures	14/19 (74%)	55/143 (38%)	**.006**
Patients with 1 adjunctive procedure	6/14 (43%)	46/55 (84%)	**.004**
Patients with >1 adjunctive procedure	8/14 (57%)	9/55 (16%)	**.004**
Total number of adjunctive procedures	25	64	

Description of Problem	Procedure			
Small or tortuous Iliac/femoral artery access	Iliofemoral bypass	3/25 (12%)	34/64 (53%)	**<.001**
	Endoconduit			
	Aortofemoral bypass			
	Iliac stenting			
Branch vessel flow restriction	Visceral/renal artery angioplasty/stent placement	3/25 (12%)	26/64 (41%)	**.01**
Proximal extent of disease	Subclavian revascularization	5/25 (20%)	4/64 (6%)	.11
	TEVAR			
	Subclavian revascularization and TEVAR			
Distal extent of disease	Common iliac artery transection and cross femoral bypass	7/25 (28%)	0/64 (0%)	**<.001**
	External to internal iliac artery bypass			
	External to internal iliac artery stent with cross femoral artery bypass			
	Bifurcated common iliac artery stent graft			
	Iliofemoral bypass			
True lumen compression	Aortic fenestration	3/25 (12%)	0/64 (0%)	**.02**
	Aortic stent placement			
Aortic compartmentalization	Aortic fenestration	4/25 (16%)	0/64 (0%)	**.005**

Table III:

Summary of intraoperative variables for definitive branched repair in the cohort.

	All (n = 162)	Dissection (n=19)	No Dissection (n=143)	P value
Contrast volume, mL *	130 ± 83	138 ± 63	128 ± 86	.57
Operative time, minutes	353 ± 108	404 ± 116	345 ± 105	.09
Fluoroscopy time, minutes	122 ± 55	131 ± 50	121 ± 56	.44
Operative blood loss, mL	485 ± 504	717 ± 758	454 ± 455	.16
Procedural success	161/162 (99%)	19/19 (100%)	142/143 (99%)	1.00

*All procedures were performed with iodinaxol at a concentrationof 320 mgI/mL

Table IV:

Summary of short and long-term outcomes following MBEVAR.

	All(n = 162)	Dissection (n=19)	No Dissection (n=143)	P value
Median follow-up, years (IQR)	2.4 (0.8 – 4.7)	1.1 (0.7 – 4.0)	2.6 (0.8 – 4.9)	.48
Early postoperative events (<30 days after MBEVAR)				
Perioperative death	5 (3%)	0 (0%)	5 (4%)	1.00
Renal failure requiring dialysis	7 (4%)	1 (5%)	6 (4%)	.59
Stroke	3 (2%)	1 (5%)	2 (1%)	.31
Paraplegia	9 (6%)	1 (5%)	8 (6%)	1.00
Myocardial infarction	4 (3%)	0 (0%)	4 (3%)	1.00
Late postoperative events (>30 days after MBEVAR)				
Aneurysm-related death	9 (6%)	2 (11%)	7 (5%)	.29
Conversion to open repair	2 (1%)	0 (0%)	2 (1%)	1.00
Migration	1 (1%)	0 (0%)	1 (1%)	1.00
Type I or III endoleak	16 (10%)	3 (16%)	13 (9%)	.41
Visceral or renal branch occlusion *				
Celiac artery	4/148 (3%)	1/18 (6%)	3/130 (2%)	.41
Superior mesenteric artery	3/159 (2%)	1/19 (5%)	2/140 (1%)	.32
Right renal artery	17/149 (11%)	3/17 (18%)	14/132 (11%)	.41
Left renal artery	11/137 (8%)	0/14 (0%)	11/123 (9%)	.60

* Denominators for visceral or renal branch occlusions reflect the total number of branches placed into the specific artery within the cohort.