
Thromboembolic Complications During Endovascular Repair of Complex Aortic Aneurysms

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Introduction

Embolization of atheromatous debris is a known cause of major morbidity and mortality during complex endovascular procedures. Microembolizations of cholesterol fragments or macroscopic particles of thrombus and plaque can result in end-organ damage and loss of renal function, bowel infarction, spinal cord injury, or stroke [1–7]. Patel et al. reported the association of increased thrombus burden in the aorta as a predictor of mesenteric and renal ischemia in patients treated by fenestrated endografts [8]. In the thoracic and abdominal aorta, severe and irregular thrombus or debris has been identified as a predictor of renal deterioration, and embolic events were associated with floating thrombus [9–11]. Although assessment of aortic thrombus is done routinely as part of preoperative planning, few studies have correlated the severity of aortic wall thrombus (AWT) with specific events using a standardized classification system. This chapter summarizes current results of fenestrated and branched endovascular aortic repair (F-BEVAR) and parallel stent-grafts and presents a novel classification system to evaluate aortic wall thrombus.

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Clinical Implications

Few studies have reported specific embolic events following endovascular treatment of complex aortic aneurysms. Although most published series have included high-risk patients with multiple comorbidities, specific embolic complications are poorly reported. Acute kidney injury is the most common complication occurring in up to 40% of the patients, depending on which criteria are used to define renal dysfunction. Postoperative dialysis has been reported in 1–10% of the patients. Spinal cord injury, with transient or persistent symptoms, has been reported in up to 30% of patients with thoracoabdominal aortic aneurysms. Strokes or transient ischemic attacks are less frequent. Regarding gastrointestinal complications, the most common complication is prolonged ileus. Bowel ischemia occurs in up to 9% of the patients, whereas pancreatitis is infrequent (Table 46.1) [12–57].

Risk Stratification

None of the prior reports has described a standardized method to quantify aortic wall thrombus. We have recently analyzed 212 patients entered in a prospective database from 2007 to 2015. The study included patients treated for pararenal (PRA) or type IV thoracoabdominal aortic aneurysms (TAAAs) with F-BEVAR who had normal or relatively normal aortic segments in the arch, thoracic aorta, and above the renal arteries.

Aortic Wall Thrombus Assessment

Volumetric measurement of aortic wall thrombus (AWT) was performed using computed tomography angiography (CTA) and Terarecon Software (Fig. 46.1) in non-aneurysmal aortic segments (≤ 4 cm) of the ascending aorta and arch

Table 46.1 Operative variables and early complications of studies reporting data on fenestrated/branched endografts

First author (year)	<i>n</i>	Operative variables			30-day mortality, <i>n</i> (%)	Postoperative events, <i>n</i> (%)						
		V/P (mean)	Operative time (min)	Contrast load (ml)		AKI	Dialysis	Bowel ischemia	Ileus	Pancreat	Stroke/TIA	SCI
Eagleton (2016) [12]	354	3.7	m 360±108	m 144±78	17 (15)	18 (15)	8 (2)	2 (1)	6 (2)	1 (1)	8 (2)	31 (9)
Ferrer (2016) [13]	65	NR	NR	NR	5 (8)	NR	6 (9)	2 (3)	NR	NR	2 (3)	8 (12)
Hu (2016) [14]	15	1.9	m 238±55	m 303±56	0	2 (13)	0	0	NR	NR	0	0
Banno (2015)	80	2.4	m 191±99	m 136±84	8 (10)	10 (8)	2 (1)	7 (9)	1 (1)	0	1 (1)	3 (4)
Martin-Gonzalez (2015) [16]	225	1.9	NR	NR	14 (6)	64 (29)	1 (1)	NR	NR	NR	NR	NR
Marzelle (2015) [17]	268	3	M 197 (<i>r</i> , 150–260)	M 146 (<i>r</i> , 100–195)	26 (10)	48 (18)	15 (6)	3 (1)	NR	0	5 (2)	11 (4)
Sailer (2015)	157	NR	m 220±110	m 162±77	10 (6)	43 (28)	NR	NR	NR	NR	NR	NR
Shahverdyan (2015) [19]	35	2.4	M 188 (<i>r</i> , 111–465)	M 159 (<i>r</i> , 80–350)	1 (3)	4 (11)	0	2 (6)	NR	0	0	0
Sveinsson (2015) [23]	288	2.3	NR	NR	6 (2)	NR	NR	NR	NR	NR	NR	NR
Glebova (2015) [22]	458	NR	M 156 (IQR, 104–227)	NR	11 (2)	9 (2)	7 (2)	NR	NR	NR	4 (1)	NR
Verhoeven (2015) [24]	166	3.6	NR	M 210 (<i>r</i> , 80–500)	15 (9)	9 (5)	1 (1)	2 (1)	NR	NR	2 (1)	15 (9)
Cochemec (2015) [20]	11	3.2	NR	NR	1 (9)	NR	0	1 (9)	NR	NR	0	1 (9)
Gallito (2015) [21]	20	2.4										
Grimme (2014) [25]	138	1.8	NR	M 195 (<i>r</i> , 80–350)	2 (1)	57 (41)	2 (1)	2 (1)	NR	NR	2 (1)	0
Kristmundsson (2014, 2009) [27]	54	1.7	M 250 (<i>r</i> , 120–333)	M 270	2 (4)	19 (35)	0	1 (1)	NR	NR	0	0
Oderich (2014)	67	1.9	m 236±81	NR	1 (2)	0	0	3 (4)	1 (1)	0	1 (1)	0
Lee (2014)	15	1.7	m 282	m 123	0	NR	NR	0	NR	NR	1 (6)	0
Liao (2014) [31]	8	1.5	NR	m 90	0	NR	NR	0	NR	NR	0	0
Dijkstra (2014) [28]	25	2.2	M 240 (IQR, 190–365)	M 194 (IQR, 103–320)	1 (4)	NR	NR	1 (4)	NR	NR	0	0
Vemuri (2014) [33]	57	2	m 250±15	m 109±6	1 (2)	4 (7)	1 (2)	0	NR	NR	1 (2)	1 (2)
Kasprzak (2014) [29]	83	3.6	NR	NR	6 (7)	NR	3 (4)	3 (4)	NR	NR	3 (4)	9 (11)
Canavati (2013) [34]	53	2.1	M 300 (<i>r</i> , 210–600)	NR	2 (4)	8 (15)	0	1 (1)	0	0	1 (1)	0
Kitagawa (2013) [35]	16	2.9	M 254 (<i>r</i> , 175–503)	M 69 (<i>r</i> , 31–121)	0	0	0	0	NR	NR	0	0
Perot (2013) [36]	115	NR	NR	NR	5 (4)	22 (19)	1 (1)	NR	NR	NR	NR	NR
Suominen (2013) [37]	21	2.1	NR	NR	2 (10)	1 (5)	0	NR	NR	NR	NR	NR
Tsilimparis (2013) [38]	264	NR	m 176±102	NR	2 (1)	4 (2)	NR	NR	NR	NR	1 (1)	NR
Donas (2012) [39]	29	1.5	m 290±122	m 156±56	0	NR	0	NR	NR	NR	0	0
GLOBALSTAR (2012) [40]	318	2.3	M 240 (80–720)	NR	13 (4)	11 (3)	0	5 (2)	1 (1)	0	5 (2)	3 (1)
Metcalfe (2012) [43]	42	2.3	NR	NR	3 (7)	NR	1 (2)	0	NR	NR	0	1 (1)

(continued)

Table 46.1 (continued)

First author (year)	n	Operative variables			30-day mortality, n (%)	Postoperative events, n (%)						
		V/P (mean)	Operative time (min)	Contrast load (ml)		AKI	Dialysis	Bowel ischemia	Ileus	Pancreat	Stroke/TIA	SCI
Ferreira (2012) [41]	48	3.8	m 498 (r, 180–900)	m 160 (r, 48–295)	10 (21)	8 (17)	4 (8)	0	NR	0	3 (6)	3 (6)
Reilly (2012) [44]	81	3.8	m 370±122	m 137±82	3 (4)	21 (26)	4 (5)	NR	NR	NR	4 (5)	19 (23)
Manning (2011) [42]	20	NR	NR	NR	2 (10)	NR	1 (5)	0	NR	NR	1 (1)	0
Tambyraja (2011) [45]	29	1.7	NR	NR	0	NR	0	NR	NR	NR	NR	NR
Troisi (2011) [46]	107				2 (2)							
Amiot (2010) [47]	134	NR	M 180 (r, 85–720)	M 160 (r, 65–280)	3 (2)	13 (10)	2 (2)	0	NR	0	3 (2)	1 (1)
Verhoeven (2010) [48]	100	1.7	M 180 (r, 110–540)	m 193±50	1 (1)	NR	NR	1 (1)	NR	NR	0	0
Greenberg (2009) [49]	30	1.7	M 234 (r, 170–554)	NR	0	NR	0	0	1 (3)	0	0	0
Scurr (2008) [50]	45	1.7	M 350 (r, 240–600)	NR	2 (4)	1 (2)	0	0	NR	NR	1 (2)	0
Ziegler (2007) [51]	63	2.2	m 204±93	m 96±46	3 (5)	14 (22)	1 (2)	1 (2)	NR	NR	0	0
Roselli (2007) [52]	73	NR	m 320±106	m 210±99	4 (6)	6 (11)	1 (1)	1 (1)	NR	NR	1 (1)	2 (3)
Halak (2006) [53]	17	1.2	NR	NR	0	NR	1 (6)	NR	NR	NR	NR	NR
Muhs (2006) [54]	38	NR	m 192±65	m 182±62	1 (3)	NR	0	1 (3)	NR	NR	0	0
O'Neill (2006) [55]	119	NR	m 227±76	m 179±53	1 (1)	30 (25)	3 (2)	NR	NR	NR	NR	NR
Semmens (2006) [56]	58	2	NR	NR	2 (3)	4 (7)	0	0	NR	NR	0	1 (1)
Anderson (2001) [57]	13	2.5	NR	NR	0	NR	0	0	NR	NR	0	0

n number of patients, V/P number of fenestrations or branches per patient, AKI acute kidney injury, Pancreat pancreatitis, TIA transient ischemic attack, SCI spinal cord injury, m, mean±standard deviation, M median; r range; IQR interquartile range, NR not reported

(Segment A), descending thoracic aorta (Segment B), and renal-mesenteric aorta (Segment C). An index was calculated using the Terarecon software volumetric tool to measure AWT burden in the three segments and in the entire length of aorta starting at the aortic annulus and extending 1-cm below the renal arteries. The infra-renal aorta, which was typically affected by large aneurysm and extensive laminated thrombus, was not measured. Because it is not possible to measure the volume of the thin walled intima, media, and adventitia, an AWT index was calculated by subtracting the volume of the aortic lumen from the total aortic volume, which includes the aortic lumen, any AWT, and the intima, media, and adventitia. Therefore, the AWT index was representative of the solid portion of the aortic wall. The AWT index was presented as a percent value (AWT Index = [Total Aortic Volume – Aortic Lumen Volume / Total Aortic Volume] × 100, Fig. 46.2).

In order to facilitate assessment of AWT in clinical practice, a novel classification was proposed using a 0–10 score system to quantify thrombus type, thickness, area of involvement, circumference, and number of affected segments. The patients were classified as mild (score 0–3), moderate (score 4–8), and severe AWT (score 9 and 10, Fig. 46.3). For purposes of this classification, we analyzed the most severely affected segment of the aorta using axial cuts. The area was selected after examination of the entire length of the aorta. The final score was correlated with the AWT volume index measured in the three aortic segments and in the entire aorta to validate the proposed classification.

From the 212 patients, 98 (46%) had minimal AWT, 75 (35%) had moderate AWT, and 39 (18%) had severe AWT (Table 46.2). The proposed classification correlated with objective assessment of AWT volume using the index in all

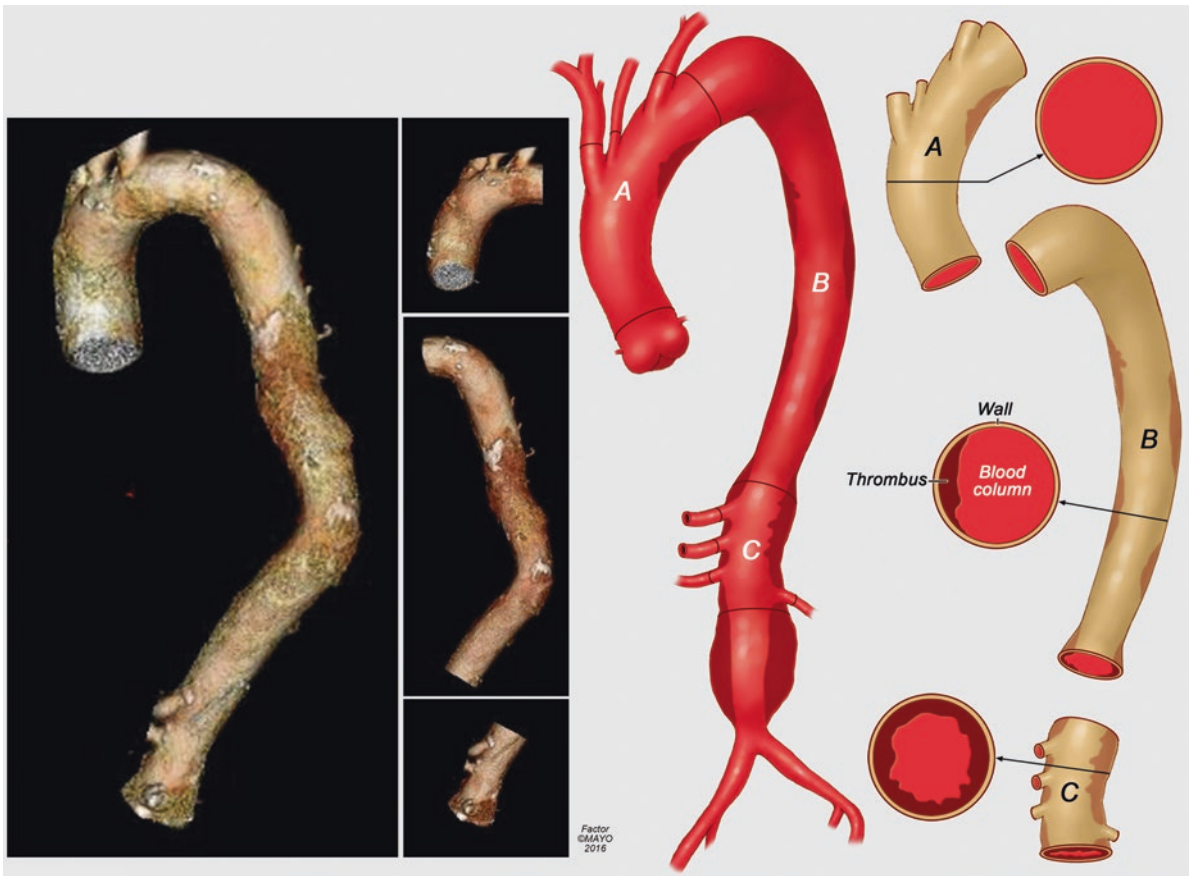
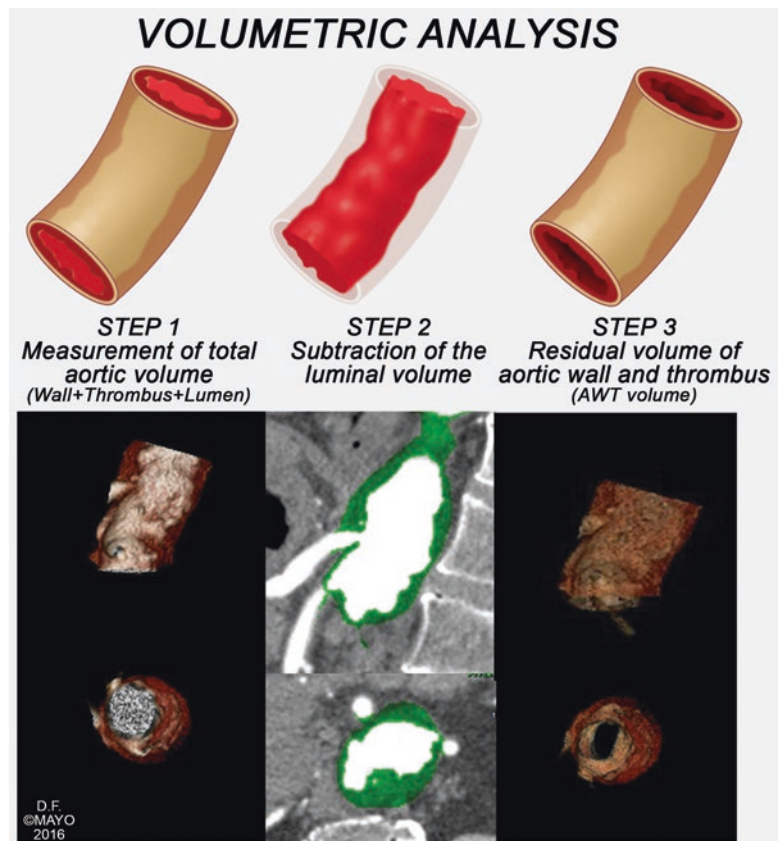


Fig. 46.1 Segmental aortic volumetric evaluation depicted as ascending and arch aorta (segment A), descending thoracic aorta (segment B) and renal-mesenteric aorta (segment C). By permission of Mayo Foundation for Medical Education and Research. All rights reserved

Fig. 46.2 Aortic wall thrombus volume measurement sequence. Total segmental volume measurement (step 1). Luminal volume subtraction (step 2). Remaining residual volume corresponding to the aortic wall and thrombus volume (step 3). By permission of Mayo Foundation for Medical Education and Research. All rights reserved










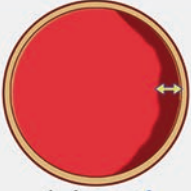
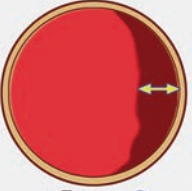
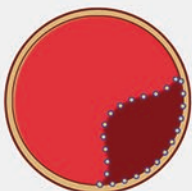
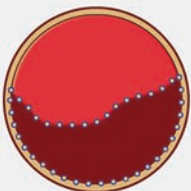
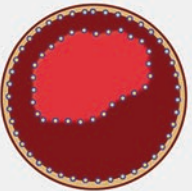
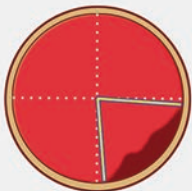
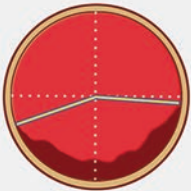
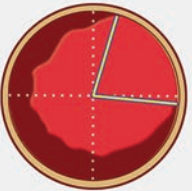
QUALITATIVE ANALYSIS				
SEGMENTS (A, B, & C)				2
	<i>None=0</i>	<i>1 segment=1</i>	<i>2-3 segments=2</i>	
THROMBUS TYPE				2
	<i>None=0</i>	<i>Smooth lining=1</i>	<i>Finger-like projections=2</i>	
THICKNESS				2
	<i>None=0</i>	<i>1-4mm=1</i>	<i>≥5mm=2</i>	
AREA				2
	<i>0-24%=0</i>	<i>25%-50%=1</i>	<i>≥50%=2</i>	
CIRCUMFERENCE				2
	<i>0-90°=0</i>	<i>91°-179°=1</i>	<i>180°-360°=2</i>	
				Total 0-10
				<p>MILD 0-3</p> <p>MODERATE 4-8</p> <p>SEVERE 9-10</p>

Fig. 46.3 Qualitative score-based classification. The most severely affected aortic area in CTA cross-section is classified for thrombus type (none, smooth lining or finger-like projections), thickness (none, 1–4 mm or ≥5 mm), area (0–24%, 25–50% or ≥50%), and circumference (0–90°, 91–179° or ≥180°). Number of affected segments is also

contemplated. Individual items are graded from 0 to 2. Mild AWT range from 0 to 4, moderate AWT from 4 to 8, and severe AWT scores 9 and 10. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

Table 46.2 Clinical postoperative events in 212 patients treated by fenestrated and branched endovascular aortic repair (F-BEVAR) for pararenal and type IV thoracoabdominal aortic aneurysms (TAAA) according to the atherosclerotic aortic wall thrombus (AWT) classification

Variable	All (n=212)	Mild (n=98)	Moderate (n=75)	Severe (n=39)	P value
	N and (percent) or mean \pm standard deviation				
Mortality (n=1)	1 (0.5)	0	1 (1.3)	0	0.71
Stroke (n=4)	4 (1.9)	1 (1)	2 (2.7)	1 (2.6)	0.46
Spinal cord injury (n=3)	3 (1.4)	0	2 (2.7)	1 (2.6)	0.16
Liver (n=3)	3 (1.4)	0 (0)	2 (2.7)	1 (2.6)	0.16
Spleen (n=25)	25 (12)	6 (6)	14 (19)	5 (13)	0.098
Kidney (n=35)	35 (17)	11 (11)	12 (16)	12 (31)	0.009
Liver-Kidney- Spleen (n=50)	50 (24)	16 (16)	20 (27)	14 (36)	0.01
Time to resume regular diet	2.9 \pm 1.7	2.5 \pm 1.4	3.1 \pm 1.8	3.4 \pm 2	0.0115
Pancreatitis (n=2)	2 (0.9)	2 (2)	0	0	0.17
Bowel ischemia (n=5)	5 (2.4)	2 (2)	2 (2.7)	1 (2.6)	0.81
RIFLE (n=45)	45 (21)	16 (16)	16 (21)	13 (33)	0.034
AKIN (n=48)	48 (23)	17 (17)	17 (23)	14 (36)	0.024
All combined (n=94)	94 (44)	34 (35)	39 (52)	21 (54)	0.016

three segments. Aortic wall thrombus index averaged $15 \pm 4\%$ for segment A, $22 \pm 5\%$ for segment B, $26 \pm 7\%$ for segment C, and $20 \pm 4\%$ for the three segments. Thirteen patients (6%) had AWT index $<15\%$.

Study Patients

From the 212 patients included in the study, there were 169 male (80%) and 43 female (20%), with mean age of 76 ± 7 years old. Aneurysm extent was PRA in 157 patients (74%) and type IV TAAA in 55 patients (26%). The maximum aneurysm diameter average was 63 ± 15 mm (Table 46.3). All procedures were performed in a hybrid endovascular room with fixed imaging unit using general endotracheal anesthesia in 210 patients (99%). Cerebrospinal fluid drainage was used in 67 patients (32%) and neuro-monitoring in 55 patients (26%). Ninety-six patients (46%) had percutaneous trans-femoral approach and 29 required iliac conduits (14%). There were 700 renal-mesenteric arteries incorporated by 609 fenestrations, 66 scallops, and 25 branches, with a mean of 3.1 ± 1 stented vessels per patient. Total volume of contrast and fluoroscopy time averaged 158 ± 63 ml and 88 ± 42 min, respectively. Technical success, defined by placement of the aortic stent and all intended side branches, was achieved in 207 patients (98%). Estimated blood loss was 757 ± 859 ml. Seventy-two patients (34%) received transfusion of packed red blood cells during the procedure (see Table 46.3). All risk factors, stent design, and procedure variables were similar in the mild, moderate, and severe AWT patients.

Clinical Events

Clinical outcomes included 30-day mortality, neurological complications (stroke and spinal cord injury), gastrointestinal (bowel ischemia, pancreatitis and time to resume regular diet) and renal injury by RIFLE and AKIN classification and decline in the estimated glomerular filtration rate (eGFR). Evidence of solid organ infarction was also reviewed in the postoperative CTA. Renal infarctions due to inadvertent occlusion of a main or accessory renal artery were excluded from analysis.

There was one 30-day mortality (0.5%) for the entire cohort, which included a patient treated for suprarenal aortic aneurysm who died from complications of a type B dissection 8 days following the initial procedure (Table 46.4). The patient had AWT index of 17% and was classified as moderate AWT. Four patients (1.9%) had strokes, which occurred in the absence of significant AWT on Segment A, although three patients had moderate to severe AWT in the thoracic or renal-mesenteric segments and one had thrombus within the innominate artery origin (Table 46.5).

Three patients (1.4%) developed SCI, including two with PRA and one with type IV TAAA. Of these, one had permanent paraplegia and two had improvements, being able to recover the ambulatory status. Patients with any SCI had higher AWT index in segment B ($28 \pm 3\%$ versus $22 \pm 5\%$) and C ($30 \pm 11\%$ versus $26 \pm 7\%$). Although there was no association of AWT index for any neurological events, six of the seven patients (86%) who developed either stroke or SCI had moderate to severe AWT scores (see Tables 46.4 and 46.5).

Table 46.3 Clinical characteristics and procedural variables in 212 patients treated by fenestrated and branched endovascular aortic repair (F-BEVAR) for pararenal and type IV thoracoabdominal aortic aneurysms (TAAA) according to atherosclerotic aortic wall thrombus (AWT) classification

Variable	All (n=212)	Mild (n=98)	Moderate (n=75)	Severe (n=39)	P value
	N and (percent) or mean ± standard deviation				
AWT index (Segment A)	15±4	13±4	14±4	17±4	<0.001
AWT index (Segment B)	22±5	20±4	22±3	27±5	<0.001
AWT index (Segment C)	26±7	23±7	26±6	32±8	<0.001
AWT index (Segments A, B and C)	20±4	18±4	21±4	24±5	<0.001
Demographics					
Age	76±7	75±7	76±7	76±6	0.62
Male	169 (80)	79 (81)	62 (83)	28 (72)	0.37
Cardiovascular risk factors					
Hypertension	188 (89)	90 (93)	64 (90)	34 (89)	0.76
Cigarette smoking	184 (87)	88 (91)	63 (89)	33 (87)	0.79
Hypercholesterolemia	171 (81)	85 (88)	56 (79)	30 (79)	0.25
Coronary Artery Disease	136 (64)	71 (73)	43 (61)	22 (58)	0.12
Chronic Obstructive Pulmonary Disease	110 (52)	55 (57)	34 (48)	21 (55)	0.51
Prior myocardial Infarction	90 (42)	44 (45)	30 (42)	16 (42)	0.9
Active Smoking	51 (24)	20 (21)	21 (30)	10 (26)	0.40
Atrial Fibrillation	45 (21)	25 (26)	14 (20)	6 (16)	0.39
Diabetes Mellitus	41 (19)	18 (19)	15 (21)	8 (21)	0.90
Arrhythmia	36 (17)	18 (19)	13 (18)	5 (13)	0.74
Congestive Heart Failure (CHF)	34 (16)	20 (21)	9 (13)	5 (13)	0.32
Stroke/TIA	33 (16)	21 (22)	10 (14)	2 (5)	0.06
Oxygen dependent	8 (4)	5 (5)	2 (3)	1 (3)	0.67
Unstable Angina	2 (1)	2 (2)	0	0	0.32
Preoperative evaluation and comorbidity scores					
Positive	51 (24)	26 (29)	18 (29)	7 (19)	0.67
Baseline Creatinine (mg/dl)	1±0.8	1±0.8	1±1	1±0.3	0.22
Baseline GFR (mL/min/1.73 m ²)	60±20	61±20	58±21	59±15	0.51
CKD Stage III–V	82 (39)	36 (37)	32 (43)	14 (36)	0.14
III	69 (33)	31 (32)	24 (32)	14 (36)	
IV	9 (4)	4 (4)	5 (7)	0	
V	4 (2)	1 (1)	3 (4)	0	
ASA Clinical Score					0.86
I	16 (8)	7 (7)	5 (7)	4 (10)	
II	94 (44)	44 (45)	33 (44)	17 (44)	
III	86 (41)	37 (38)	33 (44)	16 (41)	
IV	16 (8)	10 (10)	4 (5)	2 (5)	
SVS total score	1±0.5	1±0.5	1±0.5	1±0.5	0.60
Body Mass Index (kg/m ²)	29±6	29±6.2	28±5	28±6	0.48
Peripheral Arterial Disease	75 (35)	37 (38)	27 (38)	11 (29)	0.57
Procedure details					
Anesthesia General	210 (99)	96 (98)	75 (100)	39 (100)	0.55
Cerebrospinal Fluid Drainage	67 (32)	25 (26)	27 (36)	15 (38)	0.2
Somatosensory evoked potential (SSP)/Motor evoked potentials (MEP)	55 (26)	20 (20)	20 (27)	15 (38)	0.09
Percutaneous	96 (46)	45 (46)	28 (38)	23 (59)	0.11
Conduit	29 (14)	11 (11)	15 (21)	3 (8)	0.09
Amount of contrast used (cc)	158±63	154±67	167±62	151±55	0.34
Total fluoroscopy time (min)	88±42	87±47	91±40	86±32	0.74
Estimated blood loss (cc)	757±859	750±790	867±866	565±989	0.2
Transfusion blood products					

(continued)

Table 46.3 (continued)

Variable	All (n=212)	Mild (n=98)	Moderate (n=75)	Severe (n=39)	P value
	N and (percent) or mean ± standard deviation				
PRBC	72 (34)	34 (35)	26 (35)	12 (31)	0.9
FFP	14 (7)	6 (6)	6 (8)	2 (5)	0.81
Platelets	17 (8)	8 (8)	8 (11)	1 (3)	0.31
Cryoprecipitate	2 (1)	2 (2)	0	0	0.31
Hypogastric branches (unilateral or bilateral)	4 (2)	4 (4)	0	0	0.12
Number of vessels stented per patient (mean)	3.1 ± 1	2.9 ± 1	3.1 ± 1	3.2 ± 0.9	0.25

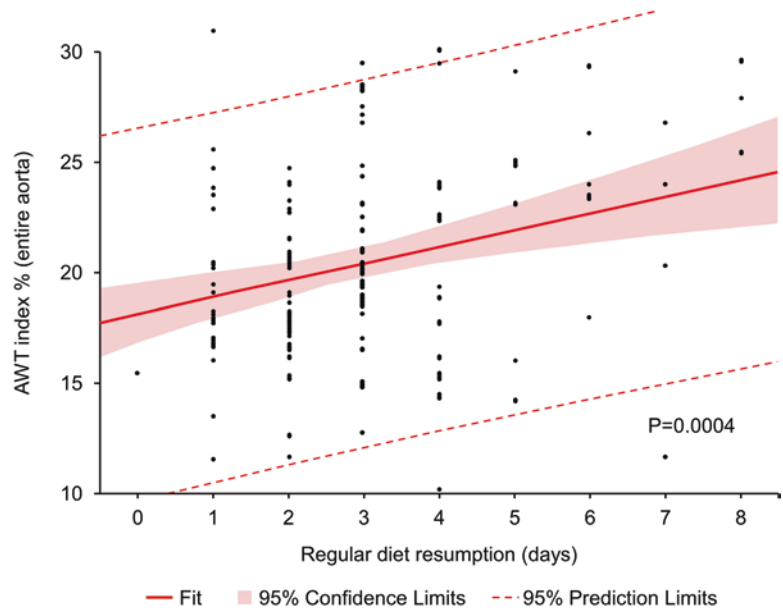
Table 46.4 Correlation of atherosclerotic aortic wall thrombus (AWT) index values (% ± SD) and clinical events in 212 patients treated by fenestrated-branched endovascular aortic repair (F-BEVAR)

Variable (N)	Segment	AWT index (% ± SD)		P value
		Yes (event)	No	
Mortality (n=1)	A	14	15 ± 4	0.78
	B	18	22 ± 5	0.39
	C	23	26 ± 7	0.66
Neurologic				
Stroke (n=4)	A	15 ± 3	15 ± 4	0.85
Spinal cord injury (n=3)	A	16 ± 5	15 ± 4	0.7
	B	28 ± 3	22 ± 5	0.11
	C	30 ± 11	26 ± 7	0.37
Solid organ infarction				
Liver (n=3)	A	17 ± 4	15 ± 4	0.24
	B	25 ± 7	22 ± 5	0.45
	C	37 ± 15	26 ± 7	0.043
Spleen (n=25)	A	16 ± 4	14 ± 4	0.2
	B	25 ± 5	22 ± 5	0.011
	C	29 ± 7	26 ± 7	0.033
Kidney (n=35)	A	16 ± 3	14 ± 4	0.039
	B	24 ± 6	22 ± 5	0.025
	C	29 ± 8	26 ± 7	0.031
Any infarction (n=50)	A	16 ± 4	14 ± 4	0.016
	B	24 ± 5	22 ± 5	0.005
	C	28 ± 8	25 ± 7	0.029
Gastrointestinal events				
Pancreatitis (n=2)	A	19	15 ± 4	0.29
	B	24	22 ± 5	0.71
	C	18 ± 6	26 ± 7	0.13
Bowel ischemia (n=5)	A	15 ± 4	15 ± 4	0.98
	B	19 ± 5	23 ± 5	0.11
	C	21 ± 3	26 ± 7	0.16
Acute renal deterioration				
RIFLE (n=45)	A	15 ± 3	14 ± 4	0.17
	B	25 ± 6	22 ± 4	0.002
	C	27 ± 8	26 ± 7	0.46
AKIN (n=48)	A	15 ± 3	15 ± 4	0.95
	B	24 ± 6	22 ± 4	0.038
	C	27 ± 8	26 ± 7	0.64
All combined (n=94)	A	15 ± 4	14 ± 4	0.07
	B	23 ± 6	22 ± 4	0.12
	C	27 ± 8	26 ± 7	0.25

Table 46.5 Renal function deterioration using the RIFLE (Risk, Injury, Failure, Loss, End Stage) and AKIN (Acute Kidney Injury) criteria in 212 patients treated by fenestrated-branched endovascular aortic repair (F-BEVAR)

AWT index (%)		Any stage	R (n=32)	I (n=8)	F (n=4)	L (n=1)	No	P value
		Mean ± standard deviation						
		Mean ± standard deviation						
RIFLE (n=45)	A	15±3	15±3	15±3	17±4	17	14±4	0.17
	B	25±6	25±5	21±6	27±7	23	22±4	0.002
	C	27±8	27±8	26±8	26±7	25	26±7	0.46
		Any stage	1 (n=39)	2 (n=7)	3 (n=2)		No	P value
		Mean ± standard deviation						
		Mean ± standard deviation						
AKIN (n=48)	A	14±3	14±4	15±4	17±0.6		15±4	0.95
	B	24±6	24±6	20±6	25±4		22±4	0.038
	C	26±8	27±8	25±8	27±4		26±7	0.64

Fig. 46.4 Linear regression analysis curve showing the association between AWT index and postoperative diet resumption. All segments were analyzed as a whole. As higher is the AWT index depicted in the y axis as longer is the time to resume the regular diet depicted in the x axis. By permission of Mayo Foundation for Medical Education and Research. All rights reserved



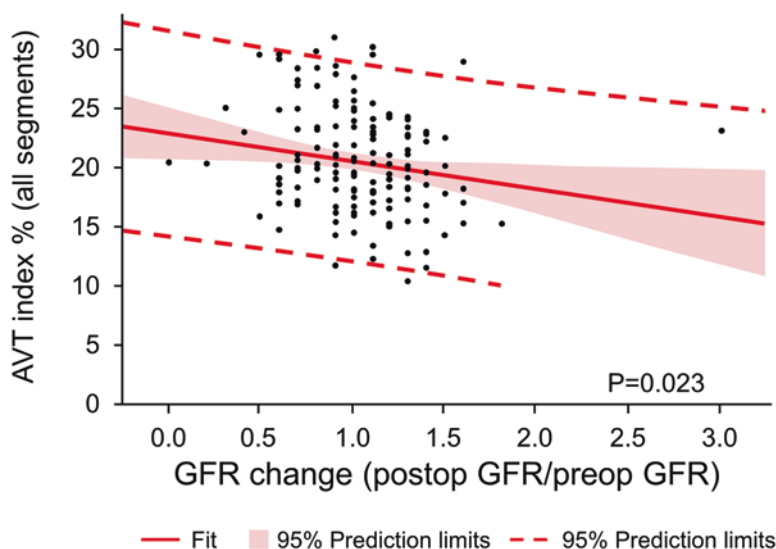
The mean time to resume a regular diet was 2.9 ± 1.7 days and was significantly longer in patients with higher AWT volume index in segment B ($P=0.018$), segment C ($P=0.0001$) and in the three segments using linear regression analysis ($P=0.0004$, Fig. 46.4). There was also longer time to resume regular diet for patients with severe and moderate thrombus burden (3.4 ± 2 and 3.1 ± 2 days versus 2.9 ± 1.7 days, $P=0.0115$). Gastrointestinal complications included ischemic colitis in four patients (1.8%) and pancreatitis in two patients (1%). There was no association between these two complications and AWT index.

Forty-five patients (21%) had acute kidney injury (AKI) using the definitions proposed by RIFLE criteria (see Table 46.4). Thirty-two patients (15%) reached the “Risk” stage, eight (4%) the “Injury” stage, four (2%) the “Failure”

stage, and one (0.5%) the “Loss” stage, requiring temporary hemodialysis. None of the patients require permanent hemodialysis. Among patients who developed acute kidney injury, AWT index was higher in segment B ($25 \pm 6\%$ versus $22 \pm 4\%$, $p=0.002$), with the highest AWT index observed for those patients who had “failure” ($27 \pm 7\%$). Results were similar using the definitions proposed by the AKIN classification, including 48 patients (23%) who had any AKI. Thirty-nine patients (18%) reached stage one, seven (3%) stage two, and two (0.9%) stage three. Segment B had the highest AWT index for patients who developed AKI ($24 \pm 6\%$ versus $22 \pm 4\%$, $p=0.04$, see Table 46.4).

There was also direct association between decline in postoperative eGFR and AWT index in segments A and B and for entire evaluated aorta (Fig. 46.5, $P=0.023$) using

Fig. 46.5 Linear regression analysis curve showing the association between AWT index and early postoperative decline in eGFR. All segments were analyzed as a whole. To evaluate the changes in the renal function, postoperative eGFR was divided by its preoperative value. By deduction, as lower is this ratio as greater is the eGFR decline. The graph depicts an inverse correlation i.e., as higher is the AWT index, as lower is the ratio and, therefore, more severe is the eGFR decline. By permission of Mayo Foundation for Medical Education and Research. All rights reserved



the linear regression analysis. Using multivariate analysis, AWT index in segment B was associated with AKI using both the RIFLE ($P=0.02$) and AKIN criteria ($P=0.0128$ and $P=0.0007$, respectively). Other independent risk factors for AKI were pre-existing CKD stage III–V and volume of contrast. AKI for was significantly more frequent in patients with moderate to severe AWT scores using either RIFLE or AKIN criteria ($P=0.034$ and $P=0.024$, respectively).

Solid organ infarctions (Fig. 46.6) were observed in 50 patients (24%). Three patients had hepatic infarction with significantly higher AWT index scores in segment C ($37\pm 15\%$ versus $26\pm 7\%$, $P=0.043$) compared to patients with no hepatic infarction (see Tables 46.4 and 46.5). Twenty-five patients (12%) had splenic infarctions with higher scores in segments B ($25\pm 5\%$ versus $22\pm 5\%$, $P=0.011$) and C ($29\pm 7\%$ versus $26\pm 7\%$, $P=0.033$) compared to patients with no splenic infarcts. Thirty-five patients (17%) had renal infarctions with higher scores in segment A (16 ± 3 versus 14 ± 4 , $P=0.039$), B (versus $24\pm 6\%$ versus 22 ± 5 , $P=0.025$), and C ($29\pm 8\%$ versus 26 ± 7 , $P=0.031$) compared to patients with no renal infarcts. The composite of any solid organ infarction was associated with higher AWT index scores for segments A ($16\pm 4\%$ versus $14\pm 4\%$, $P=0.016$), B ($24\pm 5\%$ versus $22\pm 5\%$, $p=0.005$) and C ($28\pm 8\%$ versus $25\pm 7\%$, $P=0.029$). Using multivariate analysis, AWT index in segment B was associated with solid organ embolization in all three organs ($P=0.0028$). Kidney

infarctions and any solid organ infarction were more frequent in the severe group ($P=0.009$ and $P=0.01$, respectively).

Cases Examples

Case 1

An 81-year-old male patient presented with asymptomatic type IV thoracoabdominal aneurysm with maximum diameter of 60 mm. His medical comorbidities were hypertension, congestive heart failure, hypercholesterolemia, active smoking, previous myocardial infarction and CABG, peripheral arterial disease and chronic kidney disease stage III with a baseline estimated glomerular filtration rate of 46 ml/min/1.73 m² (serum creatinine: 1.4 mg/dl). Using the preoperative risk scales, he was scored as ASA II and 17 by the SVS total score. Preoperative cardiac stress test was positive for myocardial ischemia with an ejection fraction of 43%. He had no prior aortic surgeries or other relevant surgical history.

There was significant aortic wall thrombus in the descending thoracic and renal-mesenteric aorta with a total AWT index of 29% including 31% for segment B and 47% for segment C (both in the highest quartile). Using the score-based classification he had a score of 9 (severe AWT) achieving two points for number of segments, thrombus type, thickness, circumference and 1 point for area (Fig. 46.7). He underwent a

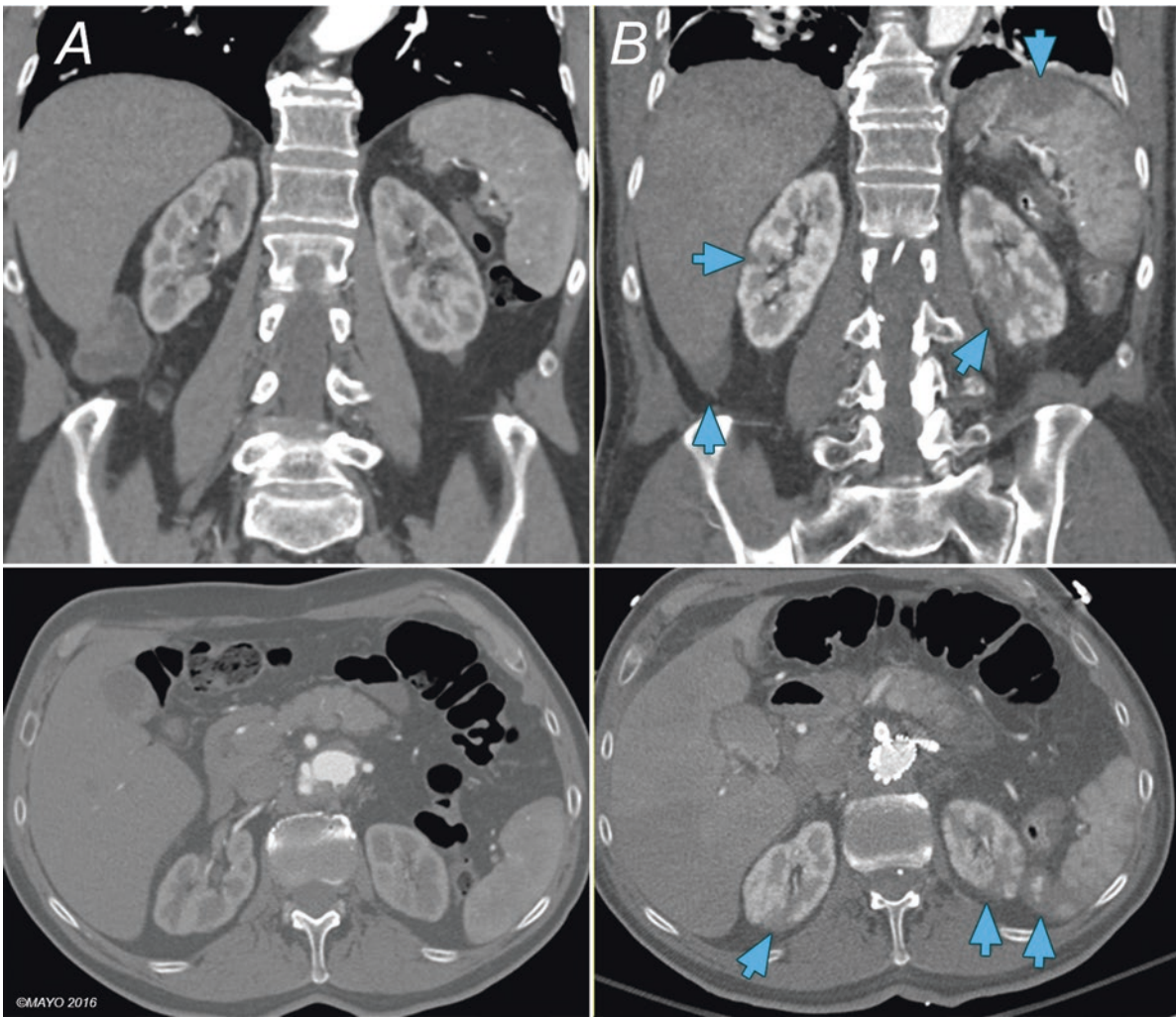


Fig. 46.6 Coronal and axial images of the preoperative (a) and early postoperative CTAs (b). Arrows depict infarction areas in liver, kidney (bilateral), and spleen. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

fenestrated endovascular repair with four-vessel incorporation by fenestrations with a customized non-standard device. There were no interferences during the procedure with a total time of 186 min and 180 ml of contrast used.

In the postoperative time, the patient presented abdominal pain and acute renal injury (AKI) with a decline in the eGFR to 20 ml/min/1.73 m², classified as “Injury” by RIFLE criteria. Postoperative CTA showed kidney, spleen, and liver infarctions (see Fig. 46.6). In the postoperative day 3, patient had troponin elevations due to a non-Q-wave myocardial infarction. He also had transitory lower limb weakness with complete recovery before discharge. ICU length of stay was 6-day long with progressive improvement of the abdominal pain and clinical condition. He had his regular diet resumed in the postoperative day 5 which was significantly longer

than the average time of 2.9 days. Total length of stay was 9 days being discharge in good conditions and with partial recovery of the renal function presenting at the dismissal a serum creatinine of 1.9 mg/dl and an eGFR of 32 ml/min/1.73 m².

Case 2

A 58-year-old male presented with an asymptomatic type IV thoracoabdominal aneurysm with maximum diameter of 57 mm. He was an active smoker and his preoperative cardiac stress test was negative with ejection fraction of 65% and normal baseline renal function. He had a history of resected prostate and testicular cancer without other prior

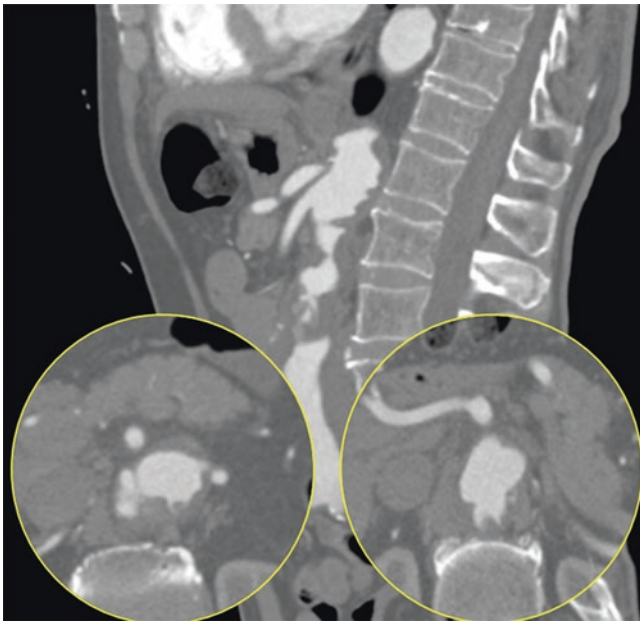


Fig. 46.7 Preoperative CTA of a patient with severe aortic wall thrombus in renal-mesenteric aorta. Thrombus severity details are depicted in the inserted images. By permission of Mayo Foundation for Medical Education and Research. All rights reserved



Fig. 46.8 Preoperative CTA showing significant aortic thrombus in the posterior aortic wall in the renal-mesenteric segment. Note its regular characteristic even though was classified as moderate due its expressive volume. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

surgeries. He was classified as ASA II and SVS score three. There was regular aortic wall thrombus mainly in renal-mesenteric aorta with a total AWT index of 23% including 25% for segment B and 41% for segment C, within the fourth quartile. Using the score-based classification he had a score of 7 (moderate AWT) achieving two points for number of segments and thickness and one point for thrombus type, circumference, and area (Fig. 46.8).

He underwent a fenestrated endovascular repair with four-vessel fenestrated component using a customized non-standard device. The length of surgery was 176 min with a total contrast volume of 170 ml without any major technical issue. Postoperative CTA showed mild spleen and left kidney infarctions (Fig. 46.9). However, there was no change in the renal function, being discharged 3 days after the procedure.

Case 3

An 84-year-old male presented with an asymptomatic parvisceral abdominal aneurysm with 59 mm in the maximum diameter. He had hypercholesterolemia and moderate pulmonary dysfunction due to asbestosis. He did not have renal dysfunction with a baseline creatinine of 0.8 mg/dl and an

eGFR of 92 ml/min/1.73 m². His SVS score was 12 mostly due to his pulmonary disease and age. No previous aortic surgeries.

There was mild to moderate aortic wall thrombus mostly in segment C with a total AWT index of 20% and an index of 26% for segment C which matches the third quartile. Using the score-based classification he had a score of 8 (moderate AWT) achieving two points for thrombus type, thickness, circumference and one point for area and number of segments (Fig. 46.10).

He underwent an endovascular repair of his aneurysm with a five-vessel fenestrated endograft with one double-scallop for celiac axis and fenestrations for superior mesenteric artery, right renal artery, and two left-sided renal arteries. Length of surgery was 300 min long (endovascular time of 251 min) with 190 ml of contrast used. The procedure did not have complications.

Postoperatively he presented mild renal deterioration reaching the stage “Risk” by RIFLE criteria with a decrease in eGFR to 55 ml/min/1.73 m². He returned to his baseline renal function before discharge. Postoperative CTA showed significant bilateral kidney infarctions mainly in the right side (Fig. 46.11). Overall he recovered well from the surgery with rapid resume of his regular diet, being discharged at postoperative day 5.

Fig. 46.9 Coronal and axial incidences of the early postoperative CTA showing wedge-shaped infarcted areas in left kidney and spleen (*arrows*). By permission of Mayo Foundation for Medical Education and Research. All rights reserved

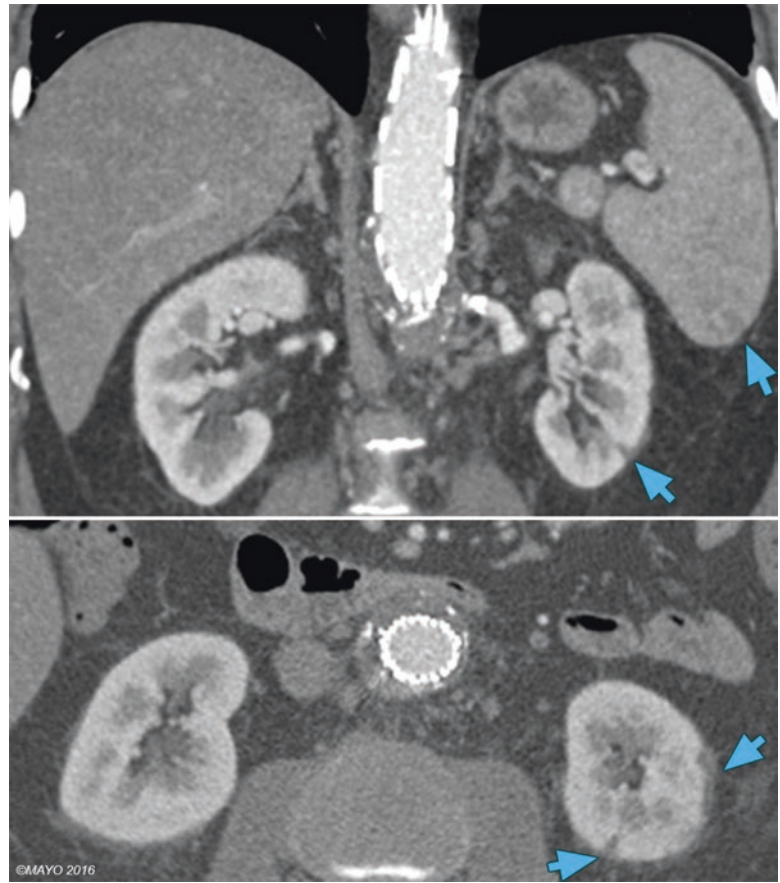


Fig. 46.10 Coronal and axial preoperative CTA images showing irregular thrombus in the renal-mesenteric aortic segment (*arrows*) that had a score eight (moderate AWT). By permission of Mayo Foundation for Medical Education and Research. All rights reserved

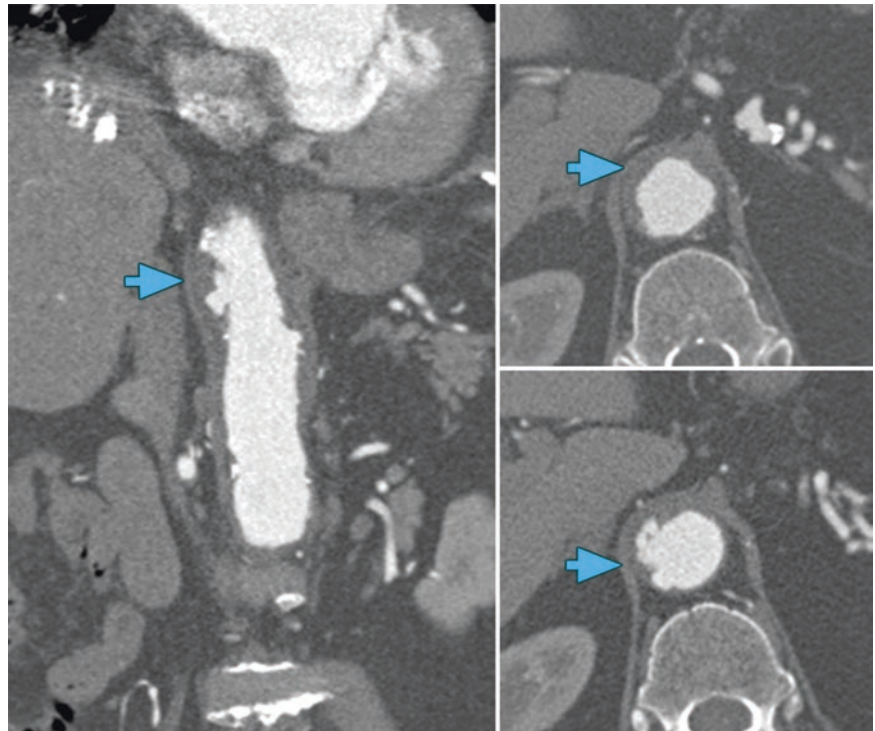
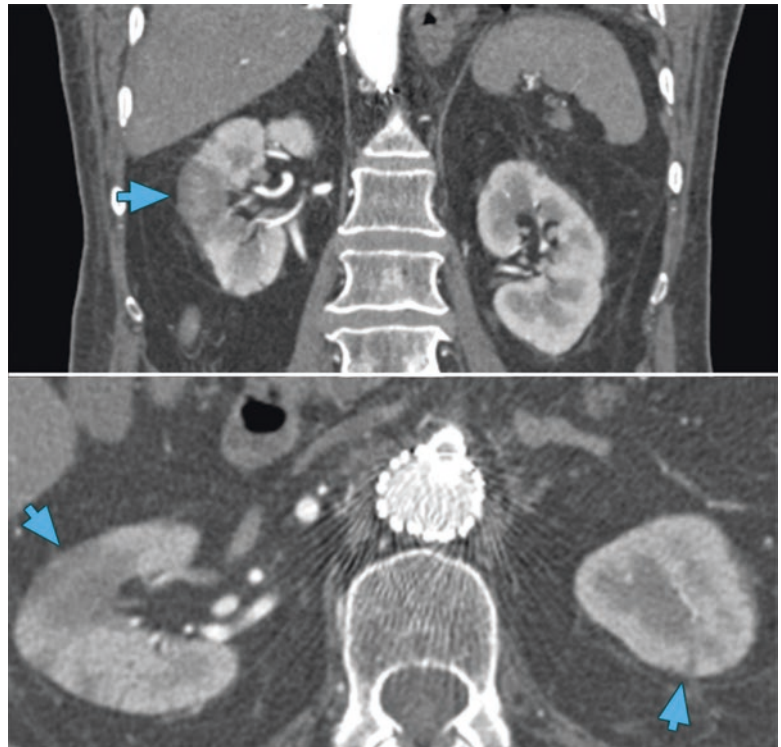


Fig. 46.11 Coronal and axial postoperative CTA images of bilateral kidney infarcts, mainly in the right side (*arrows*). Note the significant hypotenuse area in middle third of the right kidney which affected up to 30% of the kidney volume. By permission of Mayo Foundation for Medical Education and Research. All rights reserved



Case 4

A 78-year-old female patient was evaluated for a 7.2-cm type IV TAAA. Medical comorbidities included current smoking, hypertension, stage IV chronic kidney disease, and severe ischemic cardiomyopathy. She was denied treatment of her aneurysm due to extensive atherosclerotic debris in the thoracoabdominal aorta as depicted in Fig. 46.12.

Conclusion

Atherosclerotic aortic wall thrombus is a common finding in the preoperative evaluation of F-BEVAR candidates and 54% of the patients were classified as moderate and severe AWT in this study. A simple classification is proposed to stratify risk according to the amount of atherosclerotic debris in the aorta (Fig. 46.13). Management of embolization is difficult. For small debris prevention is the only effective treatment. Larger particles may be treated by catheter aspiration devices (Fig. 46.14) with careful attention to avoid vessel perforation (Fig. 46.15) which can further result in end-organ ischemia. Volumetric AWT evaluation is a reliable measurement and correlates with adverse events after F-BEVAR and has excellent correlation with the proposed classification. Therefore, AWT burden correlates with renal function deterioration, longer time to resume enteral diet, and more solid organ infarcts. Assessment of AWT should be part of preoperative planning and therapeutic decision-making in patients with complex aortic aneurysms.

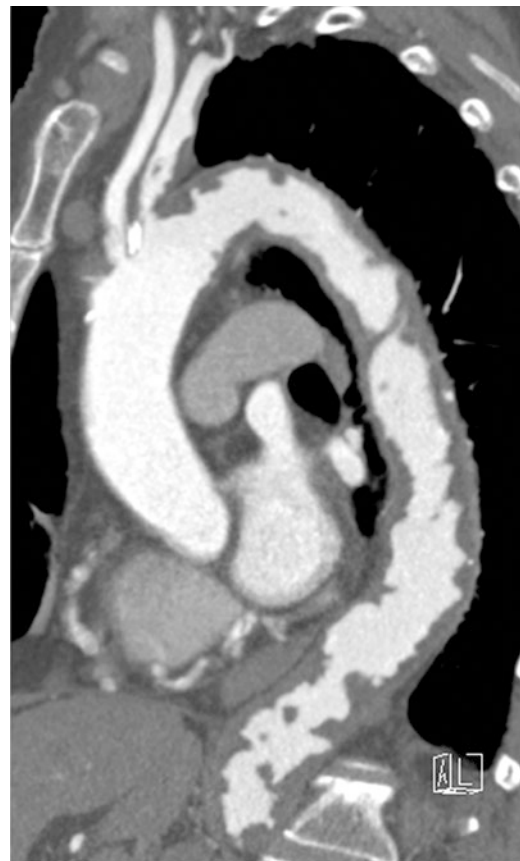


Fig. 46.12 Sagittal CTA section depicting extremely severe debris in arch, and descending aorta which carries prohibitive risk for endovascular procedures. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

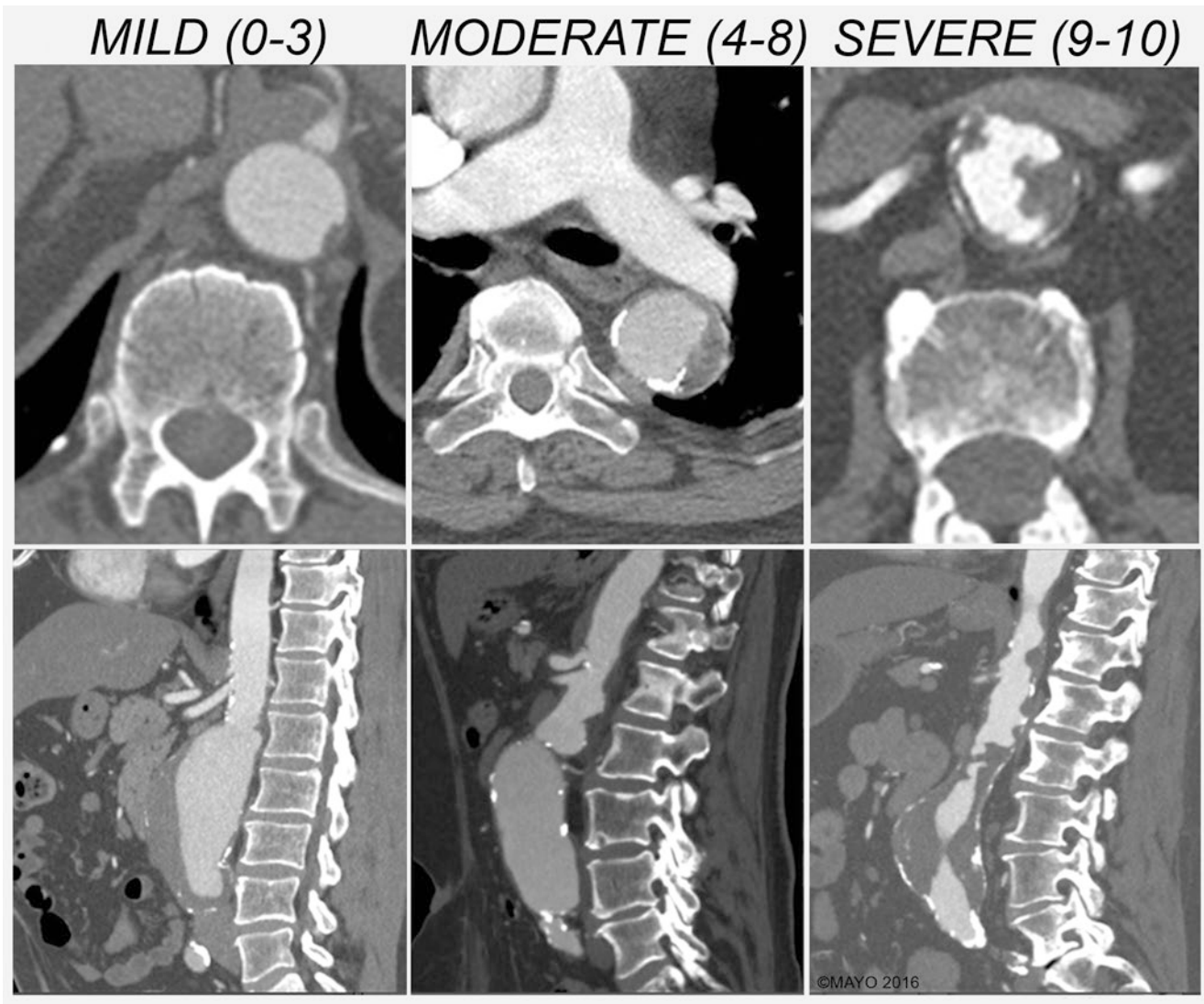


Fig. 46.13 Axial and sagittal CTA sections exemplifying all three aortic wall thrombus graduations by the proposed classification. Mild AWT patients have very slight and regular atheroma plaques without diffuse disease. Moderate AWT patients usually have higher amount of

debris with or without finger-like thrombus, whereas severe ones have extremely irregular, large, and diffuse thrombus. By permission of Mayo Foundation for Medical Education and Research. All rights reserved

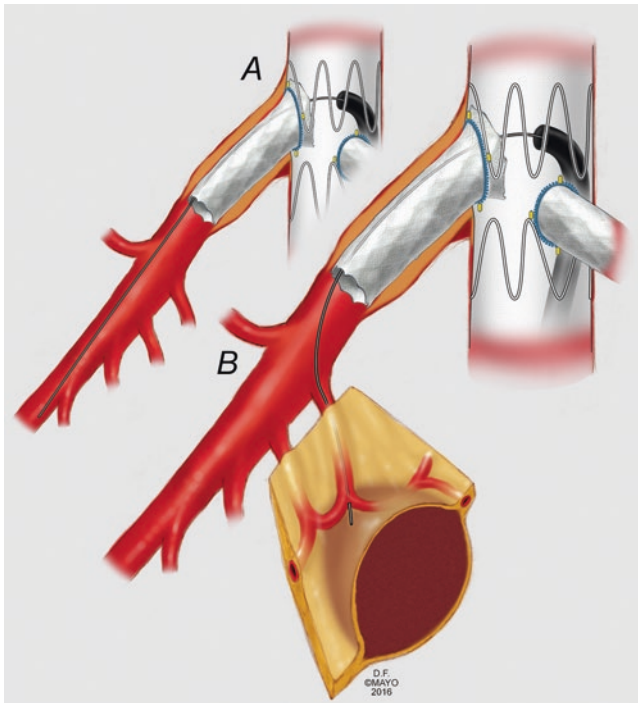


Fig. 46.15 Side-branch catheterization (a) depicting a branch mesenteric artery perforation by the guidewire tip resulting in mesenteric hematoma (b). By permission of Mayo Foundation for Medical Education and Research. All rights reserved

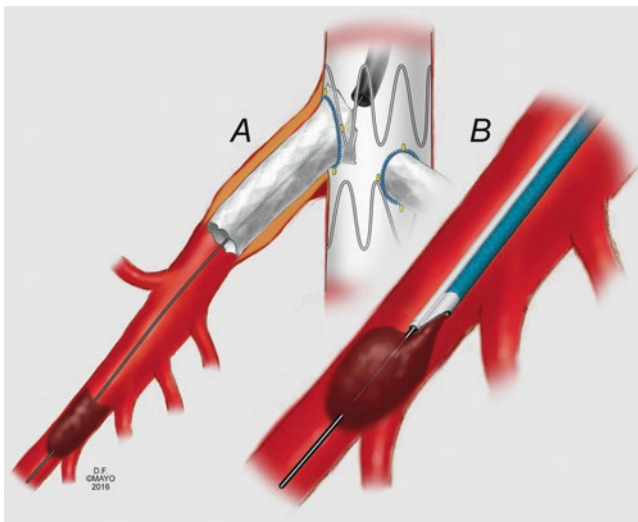


Fig. 46.14 Side-branch macroembolizations may be treated intraoperatively by suction catheters as depicted here. First, the partially or totally occluded segment has to be crossed by the guidewire (a). Sequentially, using specific catheter aspiration devices, the fresh thrombus can be aspirated as demonstrated (b). By permission of Mayo Foundation for Medical Education and Research. All rights reserved

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