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Effect of aortic angulation on the outcomes of fenestrated-branched endovascular aortic repair

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ABSTRACT

Objective: To investigate the effect of aortic angulation on the early and midterm outcomes of fenestrated-branched endovascular aneurysm repair for thoracoabdominal aortic aneurysms (TAAA) or pararenal aortic aneurysms (PRAA).

Methods: We retrospectively reviewed the data of consecutive patients enrolled in a prospective nonrandomized physician-sponsored investigational device exemption study (2013-2018). The infrarenal, suprarenal, and supraceliac aortic angles were measured on three-dimensional reconstructions of the preoperative computed tomography angiogram; a 45° cutoff was used for the analysis. Endpoints were technical success, freedom from endograft-related complications (defined by type IA/IB/IIIA/IIIB/IIID endoleaks, and limb thrombosis); and freedom from target vessel instability (defined by branch-related death, occlusion, rupture or reintervention for stenosis, endoleak, or disconnection). Cox proportional hazard multivariable regression analyses were preformed to assess impact of covariates.

Results: There were 298 patients treated for 102 PRAAs (34%) and 196 TAAAs (66%) (78 extent IV, 118 extent I-III) with 1156 renal-mesenteric vessels incorporated. An angulation of >45° was present in the infrarenal aortic axis in 94 patients (32%), suprarenal axis in 39 (13%), and supraceliac axis in 93 (31%). A supraceliac angle of >45° was more common with extent I-III TAAAs ($P = .01$). Technical success was 97% and was not significantly related to aortic angulation; the total operating time and fluoroscopy time were significantly longer in patients with any aortic angulation of >45°. Freedom from endograft-related complications was 93% (95% confidence interval [CI], 90%-97%) at 42 months, and was not associated with infrarenal (HR, 1.0; 95% CI, 0.4-2.9; $P = .976$), suprarenal (HR, 1.7; 95% CI, 0.5-1.8; $P = .428$), or supraceliac (HR, 0.9; 95% CI, 0.3-2.6; $P = .886$) aortic angles of >45°. Overall freedom from target vessel instability was 92% (95% CI, 90%-94%) at 42 months. By multivariable analysis, target vessel instability was not affected by an infrarenal angle of >45° (HR, 1.5; 95% CI, 0.9-2.4; $P = .135$) and a supraceliac angle of >45° (HR, 0.9; 95% CI, 0.5-1.5; $P = .627$), but was associated with a suprarenal angle of >45° (HR, 5.6; 95% CI, 3.5-9.1; $P < .001$), even after adjustment for aneurysm extent and type of bridging stent. In this subgroup of patients, the use of directional branch vs fenestration ($P = .10$) and the type of bridging stent ($P = .10$) did not significantly impact target vessel instability.

Conclusions: Fenestrated-branched endovascular aneurysm repair can achieve excellent early and midterm results among patients with an aortic angulation of >45°, with no increase in rates of graft-related complications. However, increased aortic angulation was associated with longer operative and fluoroscopy times. The suprarenal aortic angle was the most important determinant of more target vessel events, independent of stent design or which bridging stent was selected. (J Vasc Surg 2021;■:1-11.)

Keywords: Fenestrated endovascular aortic repair; Branched endovascular aortic repair; Juxtarenal aortic aneurysm; Thoracoabdominal aortic aneurysm; Aortic angulation; Target vessel

Excessive infrarenal and suprarenal aortic angulation have been associated with worsened outcomes in case of standard endovascular aneurysm repair (EVAR), mainly driven by an increased rate of graft migration and type IA endoleaks.[1-5] Previous studies suggested also that an increased aortic angulation modifies the mechanical forces that act on the endograft both during the deployment and the follow-up, and this phenomenon may hinder the precision of placement and the duration of sealing.[6,7]

The expansion of endovascular indications to pararenal aortic aneurysms (PRAA) and thoracoabdominal aortic aneurysms (TAAA) through fenestrated-branched EVAR (F-BEVAR)[8-11] has additional challenges. Similar to standard EVAR, a highly angulated aorta may predispose to imprecise deployment of the main endograft and compromise the apposition between the stent graft

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and the aortic wall, possibly leading to graft disconnection, fracture, and type I or III endoleaks. Furthermore, an imperfect positioning of the main stent graft may turn into a misalignment of the fenestrations and/or branches, which can result in more challenging catheterization of the target vessels. This may lead to complications such as compression, kinking, fracture, or disconnection of the bridging stents during follow-up.

However, the effect of aortic angulation on the outcomes of F-BEVAR is unclear. The purpose of this study was to investigate the impact of infrarenal, suprarenal, and supraceliac aortic angles on the early and midterm outcomes of F-BEVAR, in terms of both graft-related complications and target vessels instability, in a cohort of consecutive patients treated for PRAA or TAAA.

ARTICLE HIGHLIGHTS

- **Type of Research:** Single-center retrospective study of prospectively collected data
- **Key Findings:** Aortic angulation of >45° at the level of the infrarenal and suprarenal axis was associated with procedural metrics (increased procedural time, contrast volume, and fluoroscopy time) and lower freedom from target vessels complications over a 42 months follow-up (infrarenal angle: hazard ratio [HR], 1.0; P = .976; suprarenal angle: HR, 1.7; P = .428). The supraceliac aortic angle (HR, 0.9; P = .886) had no significant impact. Aortic angulation did not significantly affect the outcomes related to the main endograft, in terms of loss of sealing, graft tear or fracture, or limb thrombosis.
- **Take Home Message:** Fenestrated-branched endovascular aneurysm repair can achieve excellent early and midterm results among patients with an aortic angulation of >45°, with no increase in rates of graft-related complications. However, high suprarenal and infrarenal aortic angulations were associated with more target vessel events.

METHODS

All patients were enrolled prospectively in a nonrandomized investigational device exemption study on F-BEVAR (NCT1937949 and NCT2089607). The study was approved by the Mayo Clinic Institutional Review Board. Patients consented to participation in the device study and additional data collection. Additional consenting for this retrospective review was waived. F-BEVAR was performed using manufactured patient-specific or off-the-shelf endografts based on the Cook Zenith Fenestrated platform (Cook Medical Inc, Brisbane, Australia).

A retrospective review of prospectively collected data was performed on 298 consecutive patients operated between 2013 and 2018. Patients treated with physician-modified grafts were excluded, as well as urgent or emergent procedures.

Demographics, clinical characteristics, cardiovascular risk factors, and operative and postoperative variables were prospectively collected. Aneurysm classification was based on extent of aneurysmal disease evaluated by pretreatment computed tomography angiography. The early postoperative period was defined as occurring within the first 30 days or within the hospital stay if >30 days. Follow-up consisted of clinical examination, laboratory studies, and imaging before discharge and at 1, 6, and 12 months, and annually thereafter for the first 5 years. Imaging evaluation included computed tomography angiography or computed tomography scan without contrast and duplex ultrasound examination of the renal-mesenteric arteries.

Device design. Details on device design and target vessels stenting are provided elsewhere.[8-11] A proximal sealing zone of ≥25 mm was selected in normal supraceliac aortic segments, defined by parallel aortic wall with no evidence of thrombus, calcium, or diameter enlargement of >10%. Options for vessel incorporation were large (8 × 8 mm) or small fenestrations (6 × 6 mm), and directional branches (8 or 6 mm). The specific device design varied depending on the aneurysm extent, vessel angulation, and diameter of the aortic lumen. Generally, directional renal branches were used for extent I to III TAAAs, if the aortic lumen was large (>40 mm), and the target vessel orientation was downgoing without excessive tortuosity. The choice between fenestration and branch was not influenced by aortic angulation. Both patient-specific and off-the-shelf devices were used; the choice was not affected by aortic angulation, but rather by clinical characteristics and anatomic suitability.

Target vessel stenting. Catheterization and stenting of the target arteries was usually performed from a surgical brachial access. All fenestrations were stented using balloon-expandable iCAST covered stents (Maquet Atrium, Hudson, NH). The stent was deployed in order to protrude into the aorta for 3 to 5 mm; after deployment, the proximal edge was routinely flared with a 10-mm diameter balloon. Directional branches were stented using either self-expanding covered stents (Viabahn, W. L. Gore & Associates, Flagstaff, Ariz; Fluency, C. R. Bard, Inc, Tempe, Ariz; or Flair endovascular stent graft, Bard, Franklin Lakes, NJ) or balloon-expandable stent grafts (Viabahn balloon expandable VBX, W. L. Gore & Associates). The VBX balloon-expandable stent was usually preferred for the celiac trunk and superior mesenteric artery, given its specific design as bridging stent for branched devices; more conformable self-expandable stents were usually preferred for the renal arteries.[12] The cuff segment was often reinforced with a short balloon-expandable

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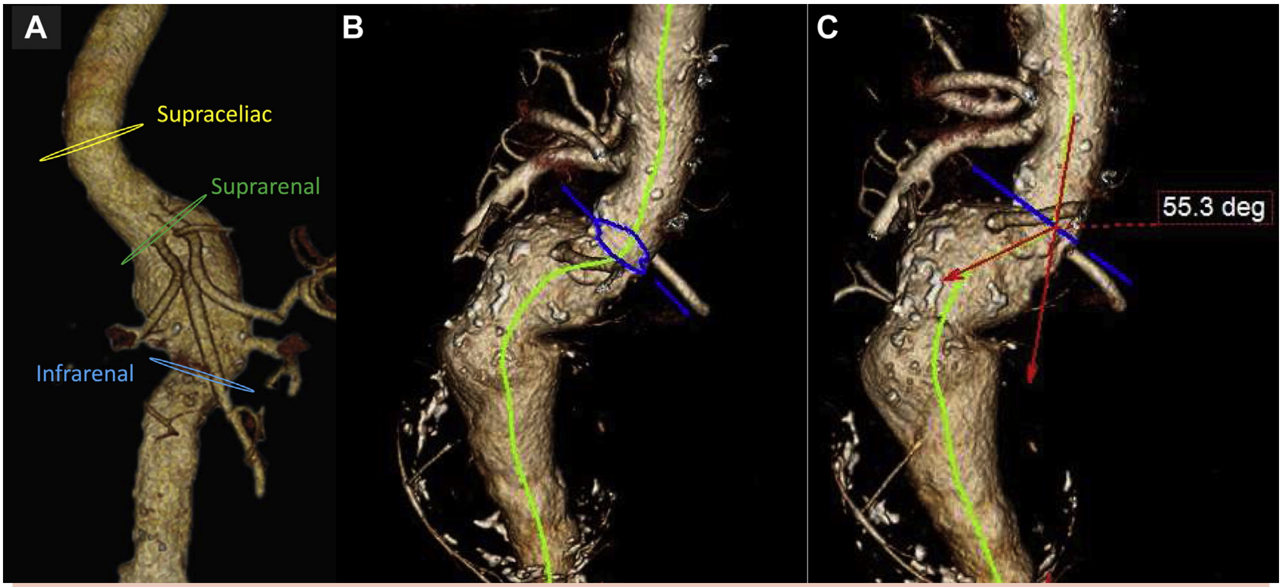

Fig 1. Example of measurement of the suprarenal aortic angle on the three-dimensional reconstructions of the preoperative computed tomography angiography (CTA). **(A)** Illustration of the identification of the infrarenal (blue), suprarenal (green), and supraceliac (yellow) angles on the three-dimensional CTA reconstruction. **(B)** After creation of the aortic centerline, the blue ring marker is positioned at the level of the aortic flexion point. **(C)** The reconstruction is turned until the ring marker appears as a straight line, indicating that the projection is perpendicular to the centerline. The three-dimensional reconstruction is then turned 360° perpendicular to the centerline at the level of the marker, and the sharpest angle is considered as the true aortic angle.

stent to prevent separation in case of self-expanding bridging stents. An adjunctive bare metal self-expandable stent was used in cases of tortuous anatomy, to accommodate to the target vessel curvature and prevent kinking at the distal edge. Technical assessment of the stented vessels included position, integrity, patency, and presence of endoleak, and was based on the completion digital subtraction angiography and a completion cone beam computed tomography scan, as previously reported.[13,14]

Aortic angulation. The infrarenal aortic angle was defined as the angle between the axis of the infrarenal aorta and the aortic axis at the level of the lower renal artery.[2] The suprarenal angle was defined as the angle between the aortic axis at the level of the higher renal artery and the axis of the suprarenal aorta.[2] The supraceliac angle was defined as the angle between the distal thoracic aorta and the visceral abdominal aorta (usually located in proximity of the diaphragmatic hiatus/distal third of the descending thoracic aorta). Any adjunctive significant angles of >45° at the level of the thoracic aorta were also recorded. A previously validated standardized method was used for the measurements to objectively quantify the three-dimensional angulation and limit the variability and approximation derived from measurements on two-dimensional reconstructions.[15] The Aquarius iNtuition software (v 4.4.13; TeraRecon, Foster City, Calif) was used to semiautomatically create the aortic centerline on volume-rendered tridimensional reconstructions and identify the predefined angles. The three-dimensional reconstruction was turned 360° perpendicular to the centerline at the levels of the aortic flexion point. The sharpest angle of the centerline was considered the true aortic angle (Fig 1). Two trained physicians (F.S. and P.B.) independently performed the measurements; the intraclass correlation coefficient to assess the interobserver agreement was 0.95. The aortic tortuosity index was measured on the three-dimensional reconstructions as well, as the ratio of the centerline distance to the straight line distance[2] between the origin of the left subclavian artery and the aortic bifurcation.

A 45° cutoff was used to stratify patients in two groups according to the severity of infrarenal, suprarenal, and supraceliac aortic angulation. This was based on the previous literature[4,5,15-17] and on a preliminary analysis on frequency density plots, stratified by endograft-related complications and target vessels complications. This process identified 45° as the optimal cutoff for the prediction of target vessels complications (Supplementary Fig 1, online only).

Endpoints. Primary endpoints were technical success,[1,2,18] freedom from endograft-related complications, and freedom from target vessel instability. Complications were defined as endograft-related if associated with failure of the aortic stent graft, and included proximal (type IA) or distal (type IB) endoleaks, endoleaks derived from incomplete attachment between two aortic components (type IIIA) or the aortic component and the iliac limbs (type IIIB), graft tear, perforation, or fracture, and limb thrombosis. Target vessel instability was defined by any target vessel-related death, occlusion, rupture or reintervention for stenosis, endoleak, or disconnection.

Secondary endpoints were procedural metrics (duration of the procedure, radiographic exposure, blood loss), major adverse events (MAE), and target vessel patency rates and freedom from related endoleaks. MAEs were defined using a composite end point, including any cause mortality, severe acute kidney injury (>50% decrease in estimated glomerular filtration rate), new-onset dialysis, myocardial infarction, respiratory failure requiring prolonged mechanical ventilation (>48 hours) or reintubation, paraplegia, stroke, bowel ischemia requiring surgical resection or intensive medical care, and estimated blood loss of >1 L. Spinal cord ischemia was classified according to the current reporting standards.[18] Target vessel primary patency was defined as uninterrupted patency from the index procedure until occlusion or any stent reintervention for stenosis. Secondary patency was defined by an occlusion treated by surgical bypass or not suitable to endovascular salvage.

Statistical analysis. Clinical and anatomic data, perioperative data, and outcomes were compared between patients with ≤45° and >45° aortic angulation at the level of the infrarenal, suprarenal and supraceliac axes. Results were reported as counts and frequencies for categorical variables, mean ± standard deviation for continuous variables. The Pearson χ^2 or Fisher exact test was used for analysis of categorical variables. Differences between continuous variables were tested with two-sided Student *t* test or Wilcoxon rank-sum test as appropriate. Time-dependent outcomes were reported using Kaplan-Meier estimates and life tables; differences were determined by the log-rank test. Univariate and multivariate Cox proportional hazards models were used to identify procedural and anatomic predictors of target vessel instability in the overall study cohort. Patients were censored at the last available follow-up visit. The unit of the analysis for branch instability was the single target vessel; because more than one event may occur in the same patient, a frailty model was used for incorporating heterogeneity between individuals using a random effect. Only a univariate analysis was performed for graft-related complications because of the low number of events and the risk of overfitting. The association between aortic angulation and relative hazard of target vessel instability was presented using penalized splines models; knots were not prespecified. A *P* value of <.05 was used to determine statistical significance. The R 3.5.2 software (R foundation for statistical computing, Vienna, Austria) was used for the analysis.

RESULTS

Patient cohort. There were 298 patients treated for 102 PRAAs (34%) and 196 TAAAs (66%) (78 extent IV and 118 extent I-III), accounting for 1156 renal-mesenteric vessels. An angulation of >45° was present in the infrarenal aortic axis in 94 patients (32%), suprarenal axis in 39 (13%), and supraceliac axis in 93 (31%). Demographics and risk factors are showed in Table I. Infrarenal and suprarenal aortic angulation were not associated with aneurysm size and extension; a supraceliac aortic angle of >45° was more frequent in large aneurysms (64.7 ± 11.1 mm vs 67.8 ± 12.2 mm; *P* = .030) and more extensive aneurysms (extent I-III TAAA, 57% vs 31%; *P* = .010) (Table II). Most patients (91%) had a brachial or axillary access and preloaded guidewires or catheters were used in 88% of patients, and this was not influenced by aortic angulations (Table III). Procedural technical success was 97.3%. The median follow-up was 24 months (interquartile range, 13-38 months). At 42 months there were 17 graft-related complications: 6 thrombosis or stenosis of the iliac limb requiring reintervention, 6 type I endoleaks (2 type IA and 4 type IB), 4 type III endoleaks, and 1 endograft infolding. The overall estimated freedom from graft-related complications was 95.1% (95% confidence interval [CI], 92-97) at 12 months, 93.1% at 24 months (95% CI, 90%-97%), and 93.1% (95% CI, 90%-97%) at 42 months. Of the 1156 incorporated target vessels, technical success was achieved in 1147 (99%). During follow-up, an occlusion or stenosis requiring reintervention occurred in 40, a branch disconnection in 2, and any branch-related endoleak requiring reintervention in 41. The overall freedom from target vessel instability was 91.6% (95% CI, 90%-94%).

Impact of infrarenal angle. Technical success was 97% for infrarenal angle of ≤45° and 99% for infrarenal angle of >45° (*P* = .240). Procedural time (177.3 ± 67.1 minutes vs 159.5 ± 59.9 minutes; *P* = .031), contrast volume (166.1 ± 64.2 mL vs 148.2 ± 51.5 mL; *P* = .014), and fluoroscopy time (90.7 ± 36.3 minutes vs 79.1 ± 29.3 minutes; *P* = .004) were significantly higher in case of infrarenal angulation of >45° (Table III), mortality (1% vs 0.5%; *P* = .573), and any MAE (34% vs 27%; *P* = .180) were similar.

There were 11 graft-related complications in patients with an infrarenal angle of ≤45° and 5 in patients with an angle of >45°. Freedom from graft complications at 42 months was similar between the two groups (93.3% [95% CI, 89%-97%] vs 92.7% [95% CI, 87%-99%]; *P* = .99).

Freedom from target vessel instability at 42 months was 93.7% (95% CI, 92%-96%) for infrarenal angulation of ≤45° and 86.8% (95% CI, 83%-91%) for angulation of >45° (*P* = .002) (Fig 2). After stratification by aneurysm extent, this difference was maintained only for PRAA (*P* = .038) and extent IV TAAA (*P* = .006) but not for extent I to III TAAA (*P* = .210). Primary patency (*P* = .030), freedom from kink or compression (*P* = .010), and

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Table I. Baseline clinical characteristics of the 298 patients undergoing fenestrated-branched endovascular aneurysm repair (F-BEVAR), stratified by infrarenal, suprarenal and supraceliac aortic angles

	Total	Infrarenal angle			Suprarenal angle			Supraceliac angle		
		≤45°	>45°		≤45°	>45°		≤45°	>45°	
	(n = 298)	(n = 204)	(n = 94)	*P* value	(n = 259)	(n = 39)	*P* value	(n = 205)	(n = 93)	*P* value
Demographics										
Age, years	74.2 ± 7.7	73.3 ± 7.5	76.2 ± 7.8	.003[a]	74.2 ± 7.5	74.4 ± 9.3	.875	73.9 ± 7.8	74.7 ± 7.6	.422
Male sex	212 (71.1)	150 (73.5)	62 (66.0)	.180	186 (71.8)	26 (66.7)	.508	146 (71.2)	66 (71.0)	.965
Risk factors										
BMI	28.1 ± 5.4	28.6 ± 5.5	27.0 ± 4.9	.024[a]	27.9 ± 5.4	29.1 ± 5.5	.213	27.7 ± 5.5	28.9 ± 5.1	.076
CAD	150 (50.3)	104 (51.0)	46 (48.9)	.743	130 (50.2)	20 (51.3)	.899	103 (50.2)	47 (50.5)	.963
CHF	30 (10.1)	24 (11.8)	6 (6.4)	.151	26 (10.0)	4 (10.3)	.966	15 (7.3)	15 (16.1)	.019[a]
Hypertension	267 (89.6)	183 (89.7)	84 (89.4)	.928	229 (88.4)	38 (97.4)	.085	182 (88.8)	85 (91.4)	.493
Hypercholesterolemia	247 (82.9)	168 (82.4)	79 (84.0)	.719	214 (82.6)	33 (84.6)	.758	164 (80.0)	83 (89.2)	.050
Smoking	245 (82.2)	170 (83.3)	75 (79.8)	.457	214 (82.6)	31 (79.5)	.633	167 (81.5)	78 (83.9)	.615
COPD	99 (33.2)	67 (32.8)	32 (34.0)	.838	85 (32.8)	14 (35.9)	.704	67 (32.7)	32 (34.4)	.769
PAD	54 (18.1)	38 (18.6)	16 (17.0)	.738	44 (17.0)	10 (25.6)	.191	34 (16.6)	20 (21.5)	.307
Diabetes	39 (13.1)	28 (13.7)	11 (11.7)	.630	31 (12.0)	8 (20.5)	.140	21 (10.2)	18 (19.4)	.031[a]
CKD	39 (13.1)	24 (11.8)	15 (16.0)	.319	31 (12.0)	8 (20.5)	.140	20 (9.8)	19 (20.4)	.011[a]
Dialysis	1 (0.3)	0 (0.0)	1 (1.1)	.140	0 (0.0)	1 (2.6)	.131	0 (0.0)	1 (1.1)	.137
Prior TIA/stroke	31 (10.4)	22 (10.8)	9 (9.6)	.751	29 (11.2)	2 (5.1)	.247	18 (8.8)	13 (14.0)	.173
Prior open aortic repair	67 (22.5)	53 (26.0)	14 (14.9)	.033[a]	59 (22.8)	8 (20.5)	.752	36 (17.6)	31 (33.3)	.003[a]
Prior endovascular aortic repair				.675			.869			.032[a]
EVAR	30 (10.1)	20 (9.8)	10 (10.6)		26 (10.0)	4 (10.3)		19 (9.3)	11 (11.8)	
TEVAR	60 (20.1)	43 (21.1)	17 (18.1)		52 (20.1)	8 (20.5)		33 (16.1)	27 (29.0)	
EVAR and TEVAR	3 (1.0)	3 (1.5)	0 (0.0)		2 (0.8)	1 (2.6)		2 (1.0)	1 (1.1)	

BMI, Body mass index; *CAD,* coronary artery disease; *CHF,* congestive heart failure; *CKD,* chronic kidney disease; *COPD,* chronic obstructive pulmonary disease; *EVAR,* endovascular aneurysm repair; *PAD,* peripheral arterial disease; *TEVAR,* thoracic endovascular aneurysm repair; *TIA,* transient ischemic attack.
Values are mean ± standard deviation or number (%).
[a]Statistically significant.

freedom from any endoleak ($P = .001$) were lower in case of infrarenal angle of >45°; there was no difference in secondary patency rates ($P = .30$) (Supplementary Table I, online only). Among patients with angulation of >45°, no procedural factors were associated with component instability, including the use of patient-specific devices (HR, 0.66; 95% CI, 0.23-1.88; $P = .439$), directional branches, (HR, 1.57; 95% CI, 0.81-3.08; $P = .184$), or balloon-expandable bridging stent (HR, 1.92; 95% CI, 0.79-4.63; $P = .147$). Following multivariate analysis, an infrarenal angle of >45° was not significantly associated with target vessel instability (HR, 1.45; 95% CI, 0.89-2.36; $P = .135$) (Table IV).

Impact of suprarenal angle. Procedural time (186.0 ± 70.8 minutes vs 162.2 ± 61.0 minutes; $P = .041$) and fluoroscopy time (93.8 ± 37.7 minutes vs 81.1 ± 30.9 minutes; $P = .023$) (Table III) were significantly higher in case of suprarenal angulation of >45°; there were no significant differences in technical success (97% vs 100%; $P = .266$), mortality (0% vs 0.8%; $P = .582$), or any MAE (36% vs 28%; $P = .298$).

During follow-up, there were 13 graft-related complications in patients with a suprarenal angle of ≤45° and 3 in patients with an angle of >45°, resulting in a similar freedom from graft complications (93.5% [95% CI, 90%-97%] vs 89.4% [95% CI, 78%-100%]; $P = .400$) at 42 months. Freedom from target vessel instability was 94.4% (95% CI, 93%-96%) for suprarenal angulation of ≤45° and 72.7% (95% CI, 65%-81%) for angulation of >45° ($P < .001$) (Fig 2, Supplementary Table II, online only); this result was maintained for PRAA ($P < .001$), extent IV ($P < .001$), and extent I to III TAAA ($P < .001$) after stratification by aneurysm extent. Primary patency ($P < .001$), secondary patency ($P = .002$), freedom from kink or compression ($P < .001$), and freedom from any related endoleak ($P < .001$) were all significantly lower in case of suprarenal angle of >45° (Supplementary Table I, online only). In the subset of patients with a >45° angle, the use of a patient-specific device (HR, 0.96; 95% CI, 0.39-2.32; $P = .930$), directional branches (HR, 1.72; 95% CI, 0.88-3.39; $P = .114$), or balloon-expandable bridging stent (HR, 1.74; 95% CI, 0.72-4.21; $P = .219$) had no significant impact on target vessel

Table II. Anatomic characteristics of the 298 patients undergoing fenestrated-branched endovascular aneurysm repair (F-BEVAR), stratified by infrarenal, suprarenal and supraceliac aortic angles

	Total	Infrarenal angle			Suprarenal angle			Supraceliac angle		
	(n = 298)	≤45° (n = 204)	>45° (n = 94)	*P* value	≤45° (n = 259)	>45° (n = 39)	*P* value	≤45° (n = 205)	>45° (n = 93)	*P* value
Aneurysm diameter, mm	65.6 ± 11.6	65.1 ± 10.6	66.9 ± 13.4	.193	65.2 ± 11.6	68.9 ± 11.2	.060	64.7 ± 11.1	67.8 ± 12.2	.030[a]
Aneurysm anatomic classification				.335			.270			.024[a]
Pararenal	102 (34.2)	66 (32.4)	36 (38.3)		93 (35.9)	9 (23.1)		80 (39.0)	22 (23.7)	
TAA	196 (65.8)	138 (67.6)	58 (61.7)		166 (64.1)	30 (76.9)		125 (61.0)	71 (76.3)	
Crawford classification				.495			.886			.010[a]
I	12 (6.1)	10 (7.2)	2 (3.4)		11 (6.6)	1 (3.3)		9 (7.1)	3 (4.2)	
II	72 (36.5)	50 (36.2)	22 (37.3)		59 (35.3)	13 (43.3)		40 (31.7)	32 (45.1)	
III	34 (17.3)	24 (17.4)	10 (16.9)		29 (17.4)	5 (16.7)		16 (12.7)	18 (25.4)	
IV	78 (39.6)	54 (39.1)	24 (40.7)		67 (40.1)	11 (36.7)		60 (47.6)	18 (25.4)	
Chronic dissection	22 (7.4)	15 (7.4)	7 (7.4)	.793	18 (6.9)	4 (10.3)	.710	15 (7.3)	7 (7.5)	.795
Celiac artery										
Diameter, mm	7.7 ± 1.4	7.7 ± 1.3	7.8 ± 1.6	.629	7.7 ± 1.4	7.8 ± 1.4	.513	7.6 ± 1.3	8.2 ± 1.5	<.001[a]
Stenosis >50%	52 (17.4)	33 (16.2)	19 (20.2)	.224	40 (15.4)	12 (30.8)	.071	33 (16.1)	19 (20.4)	.191
Superior mesenteric artery										
Diameter, mm	7.6 ± 1.1	7.7 ± 1.1	7.5 ± 1.1	.138	7.6 ± 1.1	7.7 ± 1.4	.871	7.5 ± 1.1	7.9 ± 1.2	.002[a]
Stenosis >50%	8 (2.7)	7 (3.5)	1 (1.1)	.236	6 (2.3)	2 (5.1)	.316	4 (2.0)	4 (4.4)	.231
Right renal artery										
Diameter, mm	5.6 ± 0.8	5.6 ± 0.8	5.6 ± 0.8	.997	5.6 ± 0.8	5.7 ± 0.9	.528	5.6 ± 0.7	5.6 ± 0.9	.717
Stenosis >50%	11 (3.9)	11 (5.8)	0 (0.0)	.020[a]	10 (4.1)	1 (2.7)	.677	7 (3.6)	4 (4.7)	.685
Left renal artery										
Diameter, mm	6.0 ± 3.3	6.1 ± 3.9	5.8 ± 0.6	.425	6.0 ± 3.5	5.9 ± 0.7	.805	5.8 ± 0.6	6.5 ± 5.8	.110
Stenosis >50%	20 (7.2)	10 (5.3)	10 (11.1)	.078	16 (6.6)	4 (11.1)	.326	15 (7.7)	5 (6.0)	.630

TAA, Thoracoabdominal aortic aneurysm.
Values are mean ± standard deviation or number (%).
[a]Statistically significant.

complications. Following multivariate analysis, a suprarenal angle of >45° resulted significantly associated with target vessel instability (HR, 5.62; 95% CI, 3.46-9.11; *P* < .001) after adjustment for infrarenal angulation, and type of aortic disease; balloon-expandable bridging stents (HR, 2.88; 95% CI, 1.39-5.94; *P* = .004) and extent I to III TAAA (HR, 3.00; 95% CI, 1.45-6.23; *P* = .003) had a higher risk of target vessel complications independent from aortic angulation (Table IV).

Impact of supraceliac angle. The greater prevalence of extent I to III TAAAs and larger diameter in patients with supraceliac angulation of >45° (Table II) determined a more often use of off-the-shelf devices (20% vs 7%; *P* < .001) and directional branches for the celiac artery (54% vs 31%; *P* = .001), superior mesenteric artery (54% vs 31%; *P* < .001), right renal artery (38% vs 15%; *P* < .001), and left renal artery (32% vs 16%; *P* = .007). Similarly, these patients more frequently received self-expandable bridging stents for the superior mesenteric artery (26% vs 16%; *P* = .037), right renal artery (25% vs 13%; *P* = .012), and left renal artery (27% vs 12%; *P* = .001) (Table III). Procedural time (178.6 ± 64.8 minutes vs 159.6 ± 61.1 minutes; *P* = .025) and fluoroscopy time (91.2 ± 33.3 minutes vs 79.1 ± 30.9 minutes; *P* = .003) were longer in case of supraceliac angle of >45°; the MAE rate was similar (26% vs 36%; *P* = .099).

There were 11 graft-related complications in patients with a supraceliac angle of ≤45° and 5 in patients with an angle of >45°; the estimated freedom from graft complications was similar between the two groups (92.6% [95% CI, 88%-96%] vs 94.2% [95% CI, 55%-100%]; *P* = .900). Also freedom from target vessel instability (91.6% [95% CI, 89%-94%] vs 91.5% [95% CI, 88%-96%]; *P* = .800) (Fig 2), primary patency (*P* = .800), secondary patency (*P* = .300), freedom from kink or compression (*P* = .400), and freedom from related endoleak (*P* = .700) were similar in aneurysms with a ≤45° supraceliac angulation compared with a >45° angle (Supplementary Table I, online only).

Table III. Procedural data, metrics, and early complications in the 298 patients undergoing fenestrated-branched endovascular aneurysm repair (F-BEVAR), stratified by infrarenal, suprarenal and supraceliac aortic angles

	Total	Infrarenal angle			Suprarenal angle			Supraceliac angle		
	(n = 298)	≤45° (n = 204)	>45° (n = 94)	*P* value	≤45° (n = 259)	>45° (n = 39)	*P* value	≤45° (n = 205)	>45° (n = 93)	*P* value
Procedural factors and metrics										
Endograft design				.094			.062			<.001[a]
Patient specific	264 (88.6)	185 (90.7)	79 (84.0)		233 (90.0)	31 (79.5)		190 (92.7)	74 (79.6)	
Off-the-shelf	34 (11.4)	19 (9.3)	15 (16.0)		26 (10.0)	8 (20.5)		15 (7.3)	19 (20.4)	
Preloaded catheters	153 (51.3)	110 (53.9)	43 (45.7)	.189	136 (52.5)	17 (43.6)	.299	112 (54.6)	41 (44.1)	.091
Preloaded guidewires				.462			.529			.243
Femoral	13 (4.4)	10 (4.9)	3 (3.2)		13 (5.0)	0 (0.0)		11 (5.4)	2 (2.2)	
Femoral/brachial	1 (0.3)	1 (0.5)	0 (0.0)		1 (0.4)	0 (0.0)		0 (0.0)	1 (1.1)	
Brachial	96 (32.2)	70 (34.3)	26 (27.7)		83 (32.0)	13 (33.3)		68 (33.2)	28 (30.1)	
Incorporation										
Celiac artery				.087			.551			.001[a]
No	13 (4.3)	12 (5.9)	1 (1.1)		11 (4.3)	2 (5.1)		7 (3.4)	6 (6.5)	
Fenestration	118 (39.6)	86 (42.2)	32 (34.0)		107 (41.3)	11 (28.2)		92 (44.9)	26 (28.0)	
Directional branch	114 (38.3)	76 (37.3)	38 (40.4)		95 (36.7)	19 (48.7)		64 (31.2)	50 (53.8)	
Double wide scallop	53 (17.8)	30 (14.7)	23 (24.5)		46 (17.8)	7 (17.9)		42 (20.5)	11 (11.8)	
Balloon-expandable stent	184 (61.7)	133 (65.1)	51 (54.2)	.074	162 (62.5)	22 (56.4)	.462	129 (62.9)	55 (59.1)	.533
SMA				.985			.089			<.001[a]
No	3 (1.0)	2 (1.0)	1 (1.1)		2 (0.8)	1 (2.6)		2 (1.0)	1 (1.1)	
Fenestration	182 (61.1)	124 (60.8)	58 (61.7)		164 (63.3)	18 (46.2)		140 (68.3)	42 (45.2)	
Directional branch	113 (37.9)	78 (38.2)	35 (37.2)		93 (35.9)	20 (51.3)		63 (30.7)	50 (53.8)	
Balloon-expandable stent	242 (81.2)	169 (82.8)	73 (77.7)	.287	211 (81.5)	31 (79.5)	.768	173 (84.4)	69 (74.2)	.037[a]
Right renal artery				.433			.097			<.001[a]
No	17 (5.7)	13 (6.4)	4 (4.3)		15 (5.8)	2 (5.1)		12 (5.9)	5 (5.4)	
Fenestration	214 (71.8)	149 (73.0)	65 (69.1)		191 (73.7)	23 (58.9)		161 (78.5)	53 (57.0)	
Directional branch	67 (22.5)	42 (20.6)	25 (26.6)		53 (20.5)	14 (35.9)		32 (15.6)	35 (37.6)	
Balloon-expandable stent	246 (83.1)	172 (84.7)	74 (79.6)	.271	215 (83.3)	31 (81.6)	.788	177 (86.8)	69 (75.0)	.012[a]
Left renal artery				.669			.097			.007[a]
No	20 (6.7)	13 (6.4)	7 (7.4)		17 (6.6)	3 (7.7)		12 (5.9)	8 (8.6)	
Fenestration	214 (71.8)	150 (73.5)	64 (68.1)		192 (74.1)	22 (56.4)		159 (77.6)	55 (59.1)	
Directional branch	63 (21.1)	40 (19.6)	23 (24.5)		49 (18.9)	14 (35.9)		33 (16.1)	30 (32.3)	
Balloon-expandable stent	249 (83.6)	172 (84.3)	77 (81.9)	.604	219 (84.6)	30 (76.9)	.231	181 (88.3)	68 (73.1)	.001[a]
Procedure technical success	290 (97.3)	197 (96.6)	93 (98.9)	.240	251 (96.9)	39 (100.0)	.266	202 (98.5)	88 (94.6)	.053
Procedural time, minutes	165.2 ± 62.7	159.5 ± 59.9	177.3 ± 67.1	.031[a]	162.2 ± 61.0	186.0 ± 70.8	.041[a]	159.6 ± 61.1	178.6 ± 64.8	.025[a]
Total contrast volume, mL	153.9 ± 56.3	148.2 ± 51.5	166.1 ± 64.2	.014[a]	152.7 ± 57.1	162.6 ± 51.1	.336	150.7 ± 54.9	161.4 ± 59.3	.151
Total fluoroscopy time, minutes	82.7 ± 32.1	79.1 ± 29.3	90.7 ± 36.3	.004[a]	81.1 ± 30.9	93.8 ± 37.7	.023[a]	79.1 ± 30.9	91.2 ± 33.3	.003[a]
Total radiation dose, mGy	2203 ± 1816	2135 ± 1721	2351 ± 2010	.345	2143 ± 1791	2608 ± 1954	.142	2087 ± 1787	2469 ± 1864	.096
Early complications										

(Continued on next page)

Table III. Continued.

	Total	Infrarenal angle			Suprarenal angle			Supraceliac angle		
	(n = 298)	≤45° (n = 204)	>45° (n = 94)	P value	≤45° (n = 259)	>45° (n = 39)	P value	≤45° (n = 205)	>45° (n = 93)	P value
Any MAE	86 (28.9)	54 (26.5)	32 (34.0)	.180	72 (27.8)	14 (35.9)	.298	53 (25.8)	33 (35.5)	.099
Death	2 (0.7)	1 (0.5)	1 (1.1)	.573	2 (0.8)	0 (0.0)	.582	1 (0.5)	1 (1.1)	.565
AKI	43 (14.4)	27 (13.2)	16 (17.0)	.387	35 (13.5)	8 (20.5)	.246	27 (13.2)	16 (17.2)	.359
EBL >1000 mL	30 (10.1)	18 (8.8)	12 (12.8)	.293	26 (10.0)	4 (10.3)	.966	15 (7.3)	15 (16.1)	.019[a]
Spinal cord injury, grade				.784			.489			.352
1	0 (0)	0 (0)	0 (0)		0 (0)	0 (0)		0 (0)	0 (0)	
2	5 (1.7)	4 (2.0)	1 (1.1)		4 (1.5)	1 (2.6)		2 (1.0)	3 (3.2)	
3	8 (2.7)	6 (2.9)	2 (2.1)		8 (3.1)	0 (0.0)		6 (2.9)	2 (2.2)	
Stroke/TIA	7 (2.3)	5 (2.5)	2 (2.1)	.864	6 (2.3)	1 (2.6)	.924	3 (1.5)	4 (4.3)	.134
Myocardial infarction	10 (3.4)	5 (2.5)	5 (5.3)	.201	8 (3.1)	2 (5.1)	.510	5 (2.4)	5 (5.4)	.192
Respiratory failure	6 (2.0)	2 (1.0)	4 (4.3)	.061	4 (1.5)	2 (5.1)	.137	1 (0.5)	5 (5.4)	.005[a]
GI complications	5 (1.7)	3 (1.5)	2 (2.1)	.682	3 (1.2)	2 (5.1)	.072	1 (0.5)	4 (4.3)	.018[a]

AKI, Acute kidney injury; *EBL,* estimated blood loss; *GI,* gastrointestinal; *MAE,* major adverse events; *SMA,* superior mesenteric artery; *TIA,* transient ischemic attack.
Values are mean ± standard deviation or number (%).
[a]Statistically significant.

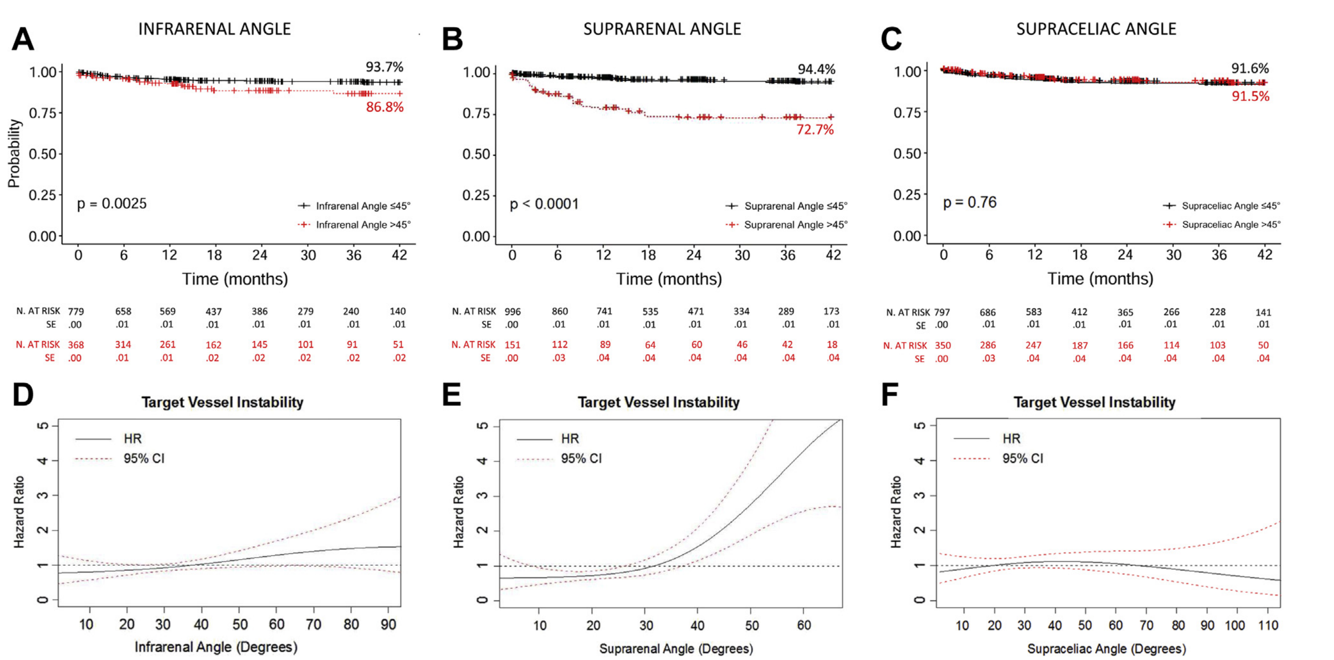

Fig 2. Impact of aortic angulation on target vessel instability. **(A)** Kaplan-Meier estimates of freedom from target vessel instability, stratified by severity of infrarenal aortic angulation. Standard error <10%. **(B)** Kaplan-Meier estimates of freedom from target vessel instability, stratified by severity of suprarenal aortic angulation. Standard error <10%. **(C)** Kaplan-Meier estimates of freedom from target vessel instability, stratified by severity of supraceliac aortic angulation. Standard error <10%. **(D)** Penalized smooth splines representing the relationship between hazard ratios for target vessel instability and infrarenal aortic angulation. $P = .005$ for the nonlinear relationship. **(E)** Penalized smooth splines representing the relationship between hazard ratios for target vessel instability and suprarenal aortic angulation. $P < .001$ for the nonlinear relationship. **(F)** Penalized smooth splines representing the relationship between hazard ratios for target vessel instability and supraceliac aortic angulation. $P = .12$ for the nonlinear relationship.

Impact of multiple aortic angulations and tortuosity index. Overall, 54 patients (18%) had multiple aortic angulations of >45°; in particular, 30 (10%) had a suprarenal and infrarenal angle of >45° and 32 (11%) had adjunctive significant angulation at the level of the thoracic aorta. Freedom from target vessel instability at 42 months

Table IV. Multivariate model of Cox proportional hazards for target vessel instability

	HR (95% CI)	*P* value
Infrarenal angle >45°	1.45 (0.89-2.36)	.135
Suprarenal angle >45°	5.62 (3.46-9.11)	<.001[a]
Aneurysm extent		
PRAA	Reference	
Extent IV	1.33 (0.66-2.68)	.419
Extent I-III	3.00 (1.45-6.23)	.003[a]
Chronic dissection	1.58 (0.82-3.08)	.174
Balloon-expandable bridging stent	2.88 (1.39-5.94)	.004[a]

CI, Confidence interval; *HR*, hazard ratio; *PRAA*, pararenal aortic aneurysm.
[a]Statistically significant.

was 94% (95% CI, 92%-99%) vs 82% (95% CI, 76%-88%) ($P < .001$) in case of multiple angulations of >45°. At the univariate analysis, the presence of multiple angulations was not associated with target vessel instability (HR, 0.67; 95% CI, 0.15-2.92; $P = .592$), but was significantly related to a greater chance of endograft-related complications (HR, 3.50; 95% CI, 2.20-5.68; $P < .001$). Similarly, aortic tortuosity index (HR, 3.16; 95% CI, 1.30-7.65; $P = .011$) had a significant impact on endograft-related complications (Supplementary Table II, online only). However, these results were not confirmed by multivariate analysis.

DISCUSSION

Data on the impact of aortic angulation on device and branch-related outcomes from F-BEVAR are scarce. Our novel analysis formally investigates the effect of aortic angulation and tortuosity on the early and midterm outcomes of F-BEVAR based on a cohort of consecutive patients treated for PRAA or TAAA within a physician-sponsored investigational device exemption trial. The results show that an excessive aortic angulation has a significant impact on procedural metrics and that infrarenal and suprarenal angles affect the durability of the stented target vessels.

These findings are consistent with preliminary reports suggesting that severe aortic angulation can pose additional technical challenges to complex endovascular aortic interventions.[11,19] However, these previous studies were not purposely focused on the impact of aortic angulation on F-BEVAR. To specifically address this topic, we selectively described the effect of infrarenal, suprarenal, and supraceliac aortic angles on both graft-related and branch-related complications; our goal was to define an angulation cutoff value associated with an increased risk of adverse perioperative and long-term outcomes.

Specifically, a suprarenal angle of >45° was the most important factor associated with target vessels events during follow-up (HR, 5.62; $P < .001$). It is interesting to note that, in cases of excessive suprarenal angulation, target vessel instability was not driven by a single specific type of complication, but by an array of adverse events (occlusion or stenosis, kink or compression, and related endoleak). The precise mechanism of failure that leads to complications in this setting is not entirely evident. However, a likely explanation includes the risk of device malrotation and misalignment during the deployment, which will result in a predisposition to stent kink, endoleak from inappropriate stent apposition, or encroaching of the bridging stent (Supplementary Fig 2, online only).

A severe aortic angulation is present in about 15% to 25% of the standard EVAR population,[4,5,20] and 10% have high suprarenal angulation[3]; although a direct comparison is not possible, these data seem to parallel our results on PRAA and TAAA. Compared with infrarenal EVAR, an infrarenal or suprarenal angulation of 45° is only relatively high; reports on EVAR include outcomes with severe neck angulation as of >60°.[3-5,20] However, different from EVAR, where the concern of neck angulation is due to the risk of type IA endoleak or infrarenal stent graft migration, angulation with F-BEVAR impacts on branch-related outcomes rather than on proximal sealing. In this context, aortic angulation may affect the outcomes in different ways, making implantation more difficult, compromising the alignment of fenestrations or branches, and adding strain into the visceral stents.[19] The fact that the implantation may be more challenging in a highly angulated aorta is confirmed by our findings of longer procedural time and higher radiation dose, which usually are the result of a more difficult cannulation of the target vessels or bridging stent delivery, more often the renal arteries. Furthermore, this result is consistent with the current instruction for use for the Zenith fenestrated endovascular graft[16] and p-Branch stent graft[17] (Cook Medical Inc), which are contraindicated in case of an infrarenal or suprarenal aortic angle of >45°.

A possible described mechanism of instability of target vessel components is through proximal graft failure, as described by O'Callaghan et al,[21] where the proximal sealing failure seems to stress the point of attachment of side branches bridging stents and threatens the overall integrity of the repair. However, in our series this did not seem to be the main mechanism leading to component instability. The rate of proximal complication was low (only two type IA endoleaks), and also the risk of separation of graft components was little and not influenced by aortic angulation. Our results may suggest that the choice of a healthy landing zone with parallel aortic walls of ≥25 mm in the supraceliac segment nearly eliminates the risk for graft-related complications that may arise from an excessive aortic angulation and indicate the use of these criteria also in case of PRAA.

Given the observation of worsened midterm outcomes in case of angulated aorta, a subgroup analysis was performed to identify any procedural factor that could improve the results in case of an infrarenal or suprarenal aortic angle of >45°. Theoretically, in this setting branched endografts may be more affected by the risk of branch kink or compression, in particular in case of a long distance between the branch gate and the target vessel, whereas fenestrated grafts may be more threatened by inaccurate alignment of fenestrations. However, no procedural factors had a significant impact. This included the use of branches vs fenestrations, endograft design, the type of bridging stent, and reinforcement with a bare metal stent. Therefore, the choice of these technical aspects should not depend on aortic angles, but rather on other factors as aneurysm extent, diameter, and side branches orientation and tortuosity, as previously reported.[9,10]

Aortic angulation has been also advocated among the possible anatomic determinants of the suitability for F-BEVAR.[22] Although our study confirms its detrimental role on midterm results, in our opinion an aortic angulation of >45° should not be considered a contraindication to F-BEVAR.[19] Despite the lower freedom from target vessel instability, an excellent technical success was achieved in all groups of patients independent from aortic angulation and tortuosity. The large use of the right arm access and preloaded catheters/guidewires may have facilitated the procedure in these challenging cases. Future studies should focus on understanding the mechanism of target vessels complications and the technical advances to improve the outcomes also in case of PRAA or TAAA with unfavorable aortic angulations.

This study has some notable limitations. This is a retrospective and single-center review that may not have generalizable results. All cases were performed by one operator (G.S.O.), limiting interprovider variability. The number of endograft-related complications was low, and thus we were unable to perform a multivariate analysis. There was a limited follow-up, and longer term results may reveal other failure modes. Our study is strengthened by the prospective collection of clinical and procedural data, the detailed and reproducible evaluation of aortic angles, and the use of standardized protocols to design the aortic stent graft and to choose the bridging stents.

CONCLUSIONS

F-BEVAR can achieve excellent early and midterm results among patients with high aortic angulation, without major differences in the rates of graft-related complications. However, increased aortic angulation was associated with higher complexity of the procedure, needing longer operative time and fluoroscopy time. A suprarenal aortic angle of >45° determined a higher risk of target vessel events, independent of stent design or which bridging stent was selected. Future studies should focus on the technical advances to achieve optimal results also in case of unfavorable aortic angulations.

AUTHOR CONTRIBUTIONS

Conception and design: FS, GO, RD
Analysis and interpretation: FS, GO, BM
Data collection: FS, PB, ET
Writing the article: FS, RD
Critical revision of the article: FS, GO, PB, ET, BM, RD
Final approval of the article: FS, GO, PB, ET, BM, RD
Statistical analysis: FS
Obtained funding: Not applicable
Overall responsibility: RD

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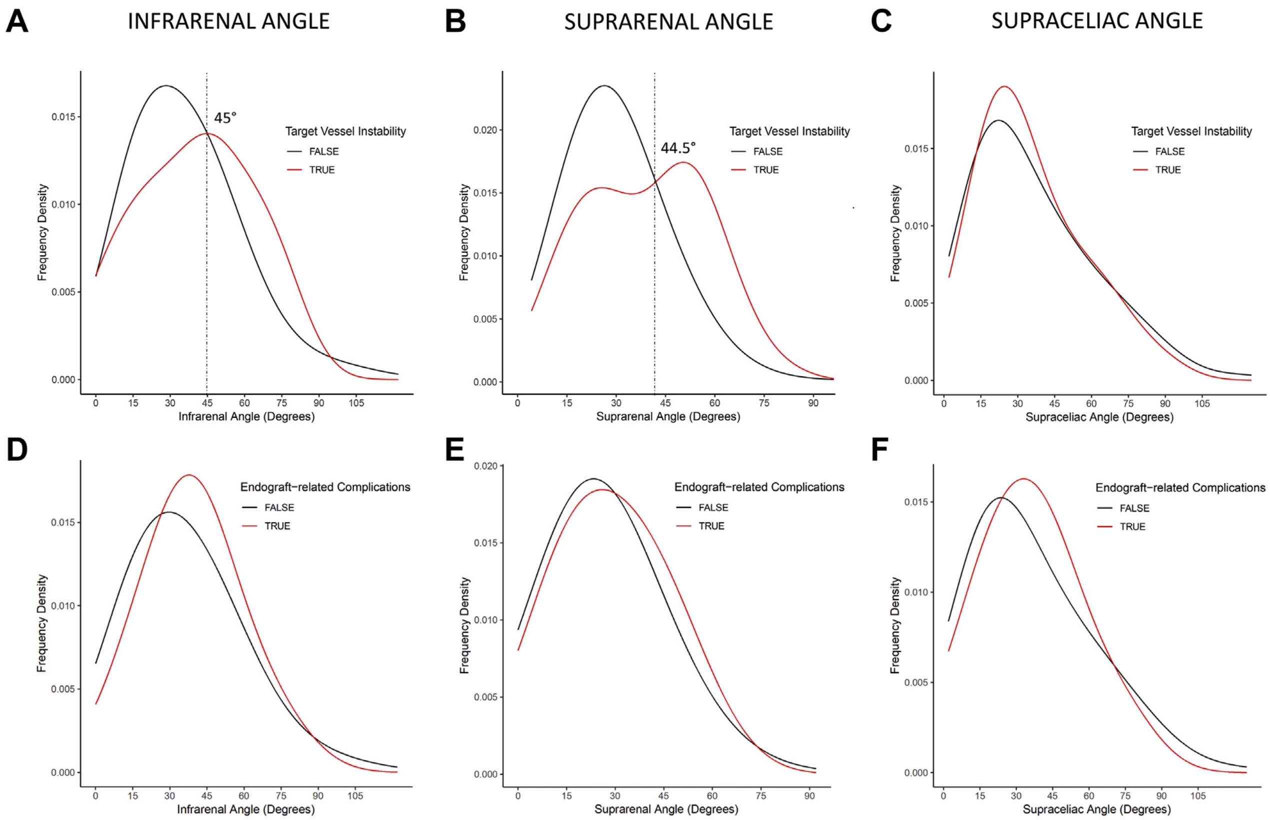
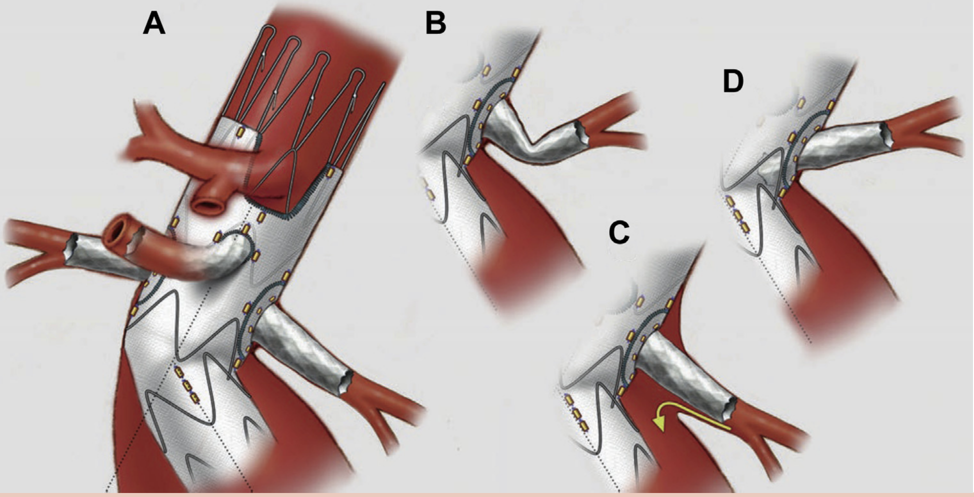


Supplementary Fig 1 (online only). Preliminary analysis for the determination of the optimal aortic angle cutoff associated with target vessels or endograft related complications. **(A)** Kernel density plots of infrarenal aortic angulation, stratified by target vessel instability during follow-up. **(B)** Kernel density plots of suprarenal aortic angulation, stratified by target vessel instability during follow-up. **(C)** Kernel density plots of supraceliac aortic angulation, stratified by target vessel instability during follow-up. **(D)** Kernel density plots of infrarenal aortic angulation, stratified by endograft-related complications during follow-up. **(E)** Kernel density plots of suprarenal aortic angulation, stratified by endograft-related complications during follow-up. **(F)** Kernel density plots of supraceliac aortic angulation, stratified by endograft-related complications during follow-up.



Supplementary Fig 2 (online only). Example of the mechanisms implied in the worse target vessels outcomes observed in patients with severe aortic angulation. **(A)** Implantation of a fenestrated endograft. **(B)** Kink of the bridging stent. **(C)** Endoleak with inappropriate stent apposition. **(D)** encroaching of the bridging stent, which could lead to branch occlusion.By permission of Mayo Foundation for Medical Education and Research. All rights reserved.

Supplementary Table I (online only). Specific 42-months rates of primary patency, secondary patency and freedom from kink or compression or endoleak requiring reintervention in the 298 patients (1147 incorporated target vessels) treated with fenestrated-branched endovascular aneurysm repair (F-BEVAR), stratified by infrarenal, suprarenal and supraceliac aortic angles

	Total	Infrarenal angle			Suprarenal angle			Supraceliac angle		
	(n = 1147)	≤45° (n = 779)	>45° (n = 368)	*P* value	≤45° (n = 996)	>45° (n = 151)	*P* value	≤45° (n = 797)	>45° (n = 350)	*P* value
Primary patency, %	95.1 (94-97)	96.7 (95-98)	91.3 (87-96)	.030[a]	97.0 (96-98)	82.6 (76-90)	<.001[a]	95.0 (93-97)	95.3 (93-98)	.800
Secondary patency, %	98.9 (98-100)	97.8 (96-100)	99.4 (99-100)	.300	98.6 (97-100)	96.2 (93-99)	.002[a]	98.3 (97-100)	98.2 (97-100)	.300
Freedom from kink/ compression, %	97.1 (96-98)	98.2 (97-99)	94.5 (92-98)	.010[a]	98.5 (97-99)	86.9 (80-94)	<.001[a]	97.3 (96-99)	96.6 (94-99)	.400
Freedom from endoleak, %	95.2 (94-97)	96.8 (95-98)	91.4 (88-95)	.001[a]	96.5 (95-98)	86.0 (80-93)	<.001[a]	95.2 (93-97)	95.0 (92-98)	.700

[a] Statistically significant.

Supplementary Table II (online only). Univariate Cox proportional hazards for target vessel instability and graft related complications

	Target vessel instability		Graft related complications	
	HR (95% CI)	*P* value	HR (95% CI)	*P* value
Clinical factors				
Female sex	0.61 (0.38-0.98)	.042[a]	0.83 (0.29-2.38)	.738
Age	1.01 (0.97-1.04)	.633	1.06 (0.98-1.13)	.110
BMI	0.98 (0.94-1.03)	.465	1.03 (0.95-1.12)	.469
Hypertension	4.51 (1.11-18.42)	.035[a]	0 (NA)	.999
Hypercholesterolemia	0.92 (0.49-1.69)	.777	3.18 (0.42-24.01)	.262
Smoking	0.60 (0.35-1.04)	.067	0.63 (0.20-1.96)	.428
COPD	0.91 (0.55-1.49)	.707	1.45 (0.55-3.81)	.449
DM	1.09 (0.57-2.06)	.803	1.26 (0.36-4.41)	.711
CKD	1.47 (0.93-2.33)	.100	0.39 (0.05-2.99)	.371
Dialysis	10.73 (2.63-43.83)	<.001[a]	0 (NA)	.999
CAD	0.36 (0.21-0.61)	<.001[a]	0.81 (0.31-2.09)	.658
PAD	0.60 (0.30-1.21)	.155	0.55 (0.12-2.42)	.432
Prior aortic repair	1.21 (0.77-1.92)	.410	1.16 (0.25-5.26)	.841
Anatomic factors				
Aneurysm diameter, mm	1.02 (1.01-1.04)	.006[a]	1.04 (1.01-1.07)	.009[a]
Aneurysm extent				
PRAA	Reference		Reference	
Extent IV	1.25 (0.61-2.59)	.543	NA	.999
Extent I-III	2.96 (1.64-5.32)	<.001[a]	NA	.999
Chronic dissection	2.98 (1.63-5.43)	<.001[a]	1.79 (0.41-7.83)	.436
Infrarenal angle, °	1.01 (0.99-1.02)	.567	1.01 (0.99-1.03)	.498
Infrarenal angle >45°	2.05 (1.29-3.23)	.002[a]	1.02 (0.35-2.89)	.976
Suprararenal angle, °	1.04 (1.02-1.06)	<.001[a]	1.01 (0.98-1.04)	.444
Suprararenal angle >45°	6.52 (4.11-10.33)	<.001[a]	1.66 (0.47-5.81)	.428
Supraceliac angle, °	1.00 (0.99-1.01)	.979	1.00 (0.98-1.02)	.914
Supraceliac angle >45°	0.89 (0.53-1.47)	.627	0.93 (0.33-2.63)	.886
Multiple angles >45°	0.67 (0.15-2.92)	.592	3.50 (2.20-5.68)	<.001[a]
Aortic tortuosity index[b]	1.44 (0.77-2.71)	.256	3.16 (1.30-7.65)	.011[a]
Aortic tortuosity index >1.25	1.46 (0.89-2.39)	.130	2.88 (1.11-7.53)	.030[a]
Target vessel stenosis >50	0.52 (0.16-1.64)	.261	-	-
Upward-oriented vessel	1.10 (0.67-1.78)	.699	-	-
Target artery				
CT-SMA	Reference		-	-
Renal arteries	2.72 (1.64-4.52)	<.001[a]	-	-
Procedural factors				
Off-the-shelf endograft	1.59 (0.84-3.02)	.157	1.86 (0.53-6.50)	.330
Type of incorporation				
Fenestration	Reference		-	-
Directional branch	2.01 (1.26-3.18)	.003[a]	-	-
Type of bridging stent				
Self-expandable	Reference		-	-
Balloon expandable	1.63 (0.83-3.16)	.154	-	-
Adjunctive BMS	0.81 (0.49-1.33)	.395	-	-
Bridging stent length, mm	1.01 (1.00-1.03)	.005[a]	-	-
No. of target vessels	1.23 (0.78-1.92)	.368	1.25 (0.50-3.07)	.627

BMI, Body mass index; *BMS,* bare metal stent; *CAD,* coronary artery disease; *CI,* confidence interval; *CKD,* chronic kidney disease; *COPD,* chronic obstructive pulmonary disease; *CT-SMA,* computed tomography scan of the superior mesenteric artery; *DM,* diabetes mellitus; *HR,* hazard ratio; *PAD,* peripheral arterial disease; *PRAA,* pararenal aortic aneurysm.
[a]Statistically significant.
[b]Exponentiated.