Effect of narrow paravisceral aorta on target vessel instability after fenestrated and branched endovascular aortic repair

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ABSTRACT

Objective: To investigate the effect of narrow paravisceral aorta (NPA) on target vessel instability (TVI) after fenestrated-branched endovascular aortic repair.

Methods: We conducted a single-center retrospective study (2014-2023) of patients treated by fenestrated-branched endovascular aortic repair for thoracoabdominal aortic aneurysms (TAAA) or pararenal aortic aneurysms. The paravisceral aorta was defined as the aortic segment limited by the diaphragmatic hiatus proximally and the emergence of lower renal artery distally, and was considered "narrow" in case of a minimum inner diameter of <25 mm. The minimum aortic diameter, location, longitudinal extension, angulation, calcification, and thrombus thickness of NPA were evaluated at the preoperative computed tomography angiogram. End points were 30-day technical success and freedom from TVI.

Results: There were 142 patients with JRAA/pararenal aortic aneurysm (n = 85 [59%]) and extent IV (n = 24 [17%]) or extent I-III (n = 33 [23%]) TAAA, with 513 target arteries successfully incorporated through a fenestration (n = 294 [57%]) or directional branch (n = 219 [43%]). A NPA was present in 95 patients (70%), 73 (86%) treated by fenestrated endovascular aortic repair (FEVAR) and 22 (39%) by branched endovascular aortic repair (BEVAR). The overall 30-day mortality was 2% and technical success was 99%, without differences between NPA and non-NPA (P = .99). Kaplan-Meier estimated freedom from TVI at 4 years was 82%, 81% (95% CI, 75-95) in patients with a NPA and 80% (95% CI, 68-94) and in those without NPA (P = .220). The result was maintained for both FEVAR (NPA: 81% [95% CI, 62-88]; non-NPA: 76% [95% CI, 60-99]; P = .870) and BEVAR (NPA: 77% [95% CI, 69-99]; non-NPA: 80% [95% confidence interval (CI) 66-99]; P = .100). After multivariate analysis, the concomitant presence of a NPA <20 mm and angulation of >30° was significantly associated with TVI in FEVAR (HR, 3.21; 95% CI, 1.03-48.70; P = .036), being the result mostly driven by target vessel occlusion. In BEVAR, a NPA diameter of <25 mm was not associated with TVI (HR, 2.02; 95% CI, 0.59-5.23; P = .948); after multivariate analysis, the use of outer branches in case of a NPA longitudinal extension of >25 mm (hazard ratio [HR], 3.02; 95% CI, 1.01-36.33; P = .040) and NPA severe calcification (HR, 1.70; 95% CI, 1.00-22.42; P = .048) were associated with a higher chance for TVI.

Conclusions: FEVAR and BEVAR are both feasible in cases of NPA and provide satisfactory target vessels durability. The use of outer branches should be avoided in cases with an inner aortic diameter of <25 mm with a longitudinal extension of >25 mm or moderate to severe NPA calcifications. In FEVAR, bridging stent patency may be negatively influenced by NPA of <20 mm in association with aortic angulation of >30°. (J Vasc Surg 2024;79:217-27.)

Keywords: Aortic aneurysm; Thoracoabdominal; Endovascular aneurysm repair; Bridging stent; Target vessel instability

In the last two decades, endovascular treatment of thoracoabdominal aortic aneurysm (TAAA) and juxta/pararenal aortic aneurysm has significantly evolved, thanks to its low perioperative mortality and morbidity in comparison with open surgery.[1-4] The evolution of accurate case planning, together with increments in different options for endograft customization, and the increasing number of off-the-shelf devices options, has allowed to drastically expand the role of endovascular repair both in elective and urgent cases.

However, there remain some anatomical aspects that may represent a criticism for technical success and long-term target vessel instability (TVI). The presence of a narrow aortic lumen may represent a challenge for endograft planning, deployment, and technical success

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for both fenestrated and branched endografts. The main issue in this anatomical situation is related to the lack of space for the main aortic endograft, hindering a correct orientation, accurate deployment, and/or determining the risk of bridging stent occlusion, because of kinking, compression, misalignment, or inadequate flaring. This factor may be particularly evident in the case of directional outer branches, favoring the use of inner branches in these particular anatomies.[5,6]

However, to date, the only parameter evaluated for defining a narrow aorta is a transverse diameter of <25 mm; this factor has been investigated with uncertain outcomes with outer branches, and its impact on the outcomes of fenestrations are unclear.[7] Nevertheless, other concomitant anatomical aspects may have an important role, as the aorta wall quality, angulations, narrowing extension, and type of endograft used.

The aim of this study was to investigate the effect of narrow paravisceral aorta (NPA) anatomical characteristics on the early outcomes and mid-term TVI, in patients undergoing fenestrated endovascular aortic repair (FEVAR) and branched endovascular aortic repair (BEVAR).

ARTICLE HIGHLIGHTS

- **Type of Research:** Single-center, retrospective study
- **Key Findings:** A narrow paravisceral aortic lumen of <25 mm together with a longitudinal extension of >2.5 cm (hazard ratio [HR]; 3.02; 95% confidence interval [CI], 1.01-36.33; $P = .040$) or presence of moderate to severe wall calcification (HR, 1.70; 95% CI,1.00-22.42; $P = .048$) represents a risk factor for target vessel instability when outer branches are used in BEVAR. In fenestrated endovascular aortic repair, a narrow paravisceral aortic lumen (<20 mm) in association with a >30° aortic angulation is associated with a higher risk of bridging stent occlusion (HR, 3.21; 95% CI, 1.03-48.70; $P = .036$).
- **Take Home Message:** A narrow paravisceral aorta (<25 mm) by itself is not a predictor of worse outcomes in fenestrated-branched endovascular aortic repair; however, its association with other specific anatomical factor may negatively influence target vessel stability over time. In the presence of those particular anatomical conditions, the planning, implantation, and follow-up protocol for fenestrated-branched endovascular aortic repair needs to be carefully adjusted, to favor long-term target vessel stability.

METHODS

Patient population. We conducted a retrospective chart review of consecutive patients operated between January 2014 and March 2023. Patients treated with physician-modified grafts were excluded. Institutional review board requirements were waived for this retrospective study.

Data collection and definitions. Demographics, clinical characteristics, cardiovascular risk factors, and operative and postoperative variables were collected. The anatomical extent of aneurysmal disease was evaluated by computed tomography angiography (CTA) and classified according with the current reporting standards.[2] The paravisceral aorta was defined as including zones 6 to 8.[2] NPA was defined as the presence of an inner aortic lumen diameter of <25 mm measured on orthogonal view. This a priori definition was based on the clinical practice and available literature.[7-9]

NPA characteristics. All preoperative imaging assessments were performed with the Aquarius iNtuition software (v 4.4.13; TeraRecon, Foster City, CA). The minimum aortic diameter, NPA extension, angulation, calcifications, and thrombus were evaluated. Aortic diameter was measured on orthogonal reconstructions from intima to intima, with exclusion of the thrombus and/or calcifications. In case of aortic dissection, the minor axis of the true lumen diameter was considered. Aortic segment with minimum aortic diameter was evaluated. NPA extension was defined as the longitudinal extension of aorta with a diameter of <25 mm along the aortic centerline; longitudinal extension was classified as focal if <5 mm (usually at the level of an angulation or focal aortic calcification). Aortic angulation was measured at the level of the paravisceral aorta on three-dimensional reconstructions.[10] Grade of calcification and thrombus were classified as none (<25% of aortic circumference), mild (25%-50%), moderate (50%-75%), or severe (>75%).[11] Maximum calcium and thrombus thickness were also assessed.

Device design. A proximal sealing zone of at least 20 mm in length was selected in normal suprarenal 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.

Fenestrations were preferred for juxta/pararenal aortic aneurysm. FEVAR endografts were based on the Cook Zenith (Cook Medical Inc, Brisbane, Australia) or Terumo Aortic (Shibuya, Japan) platforms. Directional branches were generally used for extent I to III TAAA, and the target vessel orientation was downgoing without excessive tortuosity. Inner branches were sometimes selected in case of inner aortic lumen of 25 to 35 mm or angulations[10] at the level of the paravisceral aorta. Custom-made branched devices were based on the Cook Zenith

(Cook Medical Inc) or Artivion E-xtra design (Kennesaw, GA, USA) platform. The outer-branched Cook T-branch (Cook Medical Inc) or inner-branched Artivion E-nside were used as off-the-shelf devices.[12] A mixed fenestrated-branched endograft custom design was used in select cases.

Target vessel stenting. Catheterization and stenting of fenestrations were usually performed from a femoral access. Fenestrations were stented using a balloon-expandable stent graft as main bridging stent. The Advanta V12/iCAST (Atrium Maquet Getinge, Hudson, NH), Lifestream (CR BARD Inc, Tempe, AZ), Begraft (Bentley InnoMed, Hechingen, Germany), Viabahn balloon-expandable stent graft (VBX, W. L. Gore & Associates, Flagstaff, AZ), and iCover (iVascular, Barcelona, Spain) were used. Starting 2019, the VBX stent gradually became the first choice, reserving the iCover for cases where a lower profile was desirable. The bridging stent was usually deployed with the aim to achieve a standard length of seal of 15 mm into the target artery and a protrusion into the aortic graft of 3 to 5 mm.[13] After deployment, the proximal edge of the stent was systematically flared using a 12 × 20-mm or 10 × 20-mm compliant balloon (Powerflex Pro PTA; Cordis, Santa Clara, CA).

Catheterization and stenting of BEVAR target vessels were usually performed from a left brachial surgical or percutaneous left axillary access. Self-expanding covered stents were preferred for the bridging of directional branches. The VBX (W. L. Gore & Associates) or Covera stents (CR Bard, Inc) were preferentially used as main bridging stents, depending on available lengths and diameters. The Fluency stent (CR Bard, Inc) was sometimes used at the beginning of the experience. The stent was usually deployed to achieve a standard seal length of 20 mm into the target artery. A shorter protrusion was occasionally required because of an early vessel bifurcation, and a longer protrusion was sometimes preferred in cases of vessel tortuosity. The cuff segment was reinforced with a short balloon-expandable covered stent if deployment of the self-expanding bridging stent did not completely overlap with the proximal branch cuff. An adjunctive relining stent (covered or bare metal) was used in cases of intraoperative evidence of branch or target artery kink or compression after stent graft implantation.[14]

Postoperative medical therapy was standardized for all patients, and consisted of dual antiplatelet therapy for 30 days with aspirin 100 mg and clopidogrel 75 mg, followed by long-term single antiplatelet therapy with aspirin.

End points. End points were technical success and freedom from TVI. Procedural technical success was defined as successful access to the arterial system, delivery and deployment of the aortic stent graft and all modular stent graft components, side branch catheterization and placement of bridging stents with restoration and maintenance of flow in all intended target vessels, absence of type Ia/Ib or type IIIa endoleaks, and patency of all aortic modular stent graft components and intended side branch components.[2] Thirty-day technical success was defined as maintenance of procedural technical success for 30 days without type Ia or type III endoleaks or TVI, confirmed by CTA. TVI was defined as a composite end point, including any death or rupture related to side branch complication, branch occlusion, or any secondary intervention indicated to treat a branch-related complication, including endoleak, disconnection, kink, stenosis, occlusion, or rupture.[2] Reintervention for target vessel stenosis was usually considered for symptomatic or severe stenosis (>70%).

Statistical analysis. Results were reported as a number and percentage for categorical variables, mean ± standard deviation or median (interquartile range) for continuous variables. Time-dependent outcomes were reported using Kaplan-Meier estimates. Univariate and multivariate Cox proportional hazards models were used to identify factors associated with freedom from TVI. The unit of the analysis for TVI was each individual target vessel. Covariates with univariate significance at a *P* value of <.200 were entered into the initial multivariate model; a backward stepwise selection of covariates was performed and the most parsimonious multivariate model with inclusion of significant factors and confounders was selected as final model. A penalized likelihood method based on Firth's regression[15] was adopted to account for the limited number of events. For continuous variables, a cutoff analysis was implemented by assessing the frequency density distributions of cases with TVI vs uncomplicated cases. The impact of paravisceral aorta diameter on HR for TVI was also assessed on penalized splines functions. In the analysis per patient, cases with a mixed fenestrated-branched graft design were classified as BEVAR or FEVAR according to the more prevalent type of target vessel incorporation. In the analysis per target vessel, the specific type of incorporation was considered. A *P* value of <.05 was used to determine statistical significance. The R 4.0.4 software (The R Foundation for Statistical Computing, Vienna, Austria) was used for analyses.

RESULTS

Patients. There were 142 patients with JRAA/pararenal aortic aneurysm (PRAA) (n = 85 [59%]), extent IV (n = 24 [17%]), or extent I to III (n = 33 [23%]) TAAA, with 513 target arteries successfully incorporated through a fenestration (n = 294 [57%]) or directional branch (n = 219 [43%]). A NPA was present in 95 patients (67%), 73 (76%) treated by FEVAR and 22 (23%) by BEVAR.

Table I. Demographics and risk factors of the 142 patients treated by fenestrated-branched endovascular aortic repair (F-BEVAR), stratified by presence of a narrow paravisceral aorta (*NPA*) (diameter of <25 mm)

Characteristics	All patients (n = 142)			FEVAR (n = 85)			BEVAR (n = 57)		
	NPA (n = 95)	No NPA (n = 47)	*P* value	NPA (n = 73)	No NPA (n = 12)	*P* value	NPA (n = 22)	No NPA (n = 35)	*P* value
Demographics									
Age, years	73.5 ± 10.0	66.8 ± 10.0	.002[a]	73.7 ± 10.0	74.1 ± 10.0	.926	73 ± 10.2	64.9 ± 10.3	.008[a]
Age >80 years	17 (18)	8 (17)	.99	12 (16)	3 (25)	.697	5 (23)	5 (14)	.485
Male sex	80 (84)	41 (87)	.803	53 (73)	10 (83)	.723	17 (77)	31 (88)	.286
Risk factors									
Hypertension	87 (92)	37 (78)	.057	67 (92)	10 (83)	.261	20 (91)	27 (77)	.287
Diabetes	16 (17)	7 (15)	.99	10 (14)	2 (17)	.675	6 (27)	5 (14)	.305
Dyslipidemia	65 (68)	25 (53)	.100	50 (68)	9 (75)	.748	15 (68)	16 (46)	.111
CAD	48 (53)	18 (34)	.211	33 (45)	5 (42)	.99	15 (68)	13 (37)	.114
COPD	15 (16)	5 (11)	.455	12 (16)	1 (8)	.682	3 (14)	4 (11)	.99
CKD	32 (34)	14 (30)	.705	23 (32)	3 (25)	.748	9 (41)	11 (31)	.571
PAD	10 (11)	2 (9)	.337	5 (7)	0 (0)	.99	5 (23)	2 (6)	.095
Prior stroke/TIA	11 (12)	4 (9)	.773	7 (10)	1 (8)	.99	4 (18)	3 (9)	.414
Prior laparotomy	36 (38)	10 (23)	.057	26 (36)	2 (17)	.321	10 (45)	8 (23)	.088
Prior aortic surgery	27 (28)	11 (23)	.553	18 (25)	2 (17)	.723	9 (41)	9 (26)	.256
SVS comorbidity score	8.0 ± 3.6	7.9 ± 3.6	.896	8.1 ± 3.6	8.5 ± 3.6	.796	7.8 ± 3.7	7.8 ± 3.7	.99

BEVAR, Branched endovascular aortic repair; *CAD*, coronary artery disease; *COPD*, chronic obstructive pulmonary disease; *CKD*, chronic kidney disease; *FEVAR*, fenestrated endovascular aortic repair; *PAD*, peripheral artery disease; *SVS*, Society for Vascular Surgery; *TIA*, transient ischemic attack.
Values are mean ± standard deviation or number (%).
[a]Statistically significant.

Five patients received a mixed fenestrated-branched endograft. The mean patient age was 72 ± 10 years and 85% of patients were male. Demographics and risk factors of the patient cohort, stratified by endograft design and presence of NPA, are reported in Table I.

Patients with a NPA were characterized by a higher prevalence of JRAA/PRAA rather than TAAA (74% vs 24%; $P < .001$), both in FEVAR (82% vs 42%; $P < .001$) and BEVAR (59% vs 20%; $P < .001$), and a steeper aortic angulation (26 ± 13° vs 19 ± 13°; $P = .013$), especially in those treated by BEVAR (FEVAR, 24 ± 14° vs 22 ± 13° [$P = .738$]; BEVAR, 30 ± 14° vs 18 ± 13° [$P = .003$]). Six patients had aortic dissection.

The anatomical details of NPA are showed in Table II. The minimum NPA aortic diameter was 20 ± 5 mm in case of FEVAR and 21 ± 5 mm in case of BEVAR. The aortic segment with minimum aortic diameter was zone 8 for most patients (45%), and the mean longitudinal extension was overall 27 ± 18 mm, 31 ± 18 mm in FEVAR and 19 ± 18 mm in BEVAR. NPA was associated with an aortic dissection with a true lumen diameter of <25 mm in 5 cases (5%), moderate/severe calcification in 10 (11%), extended thrombus in 23 (24%), and steep aortic angulation (>30°) in 24 (25%).

An off-the-shelf branched device was used in 27 patients (19%). In cases of BEVAR, the use of inner branches was preferred in case of NPA (63% vs 20%; $P = .001$); also, the use of adjunctive relining stent was more often performed for the celiac artery (38% vs 6%; $P = .009$) and superior mesenteric artery (59% vs 20%) in the case of NPA. After stratification by type of target vessel incorporation, procedural metrics were similar comparing NPA vs non-NPA for both BEVAR and BEVAR (Table II).

Early outcomes. The overall procedural technical success rate was 99%. In one case of NPA undergoing FEVAR, the left renal artery could not be successfully bridged owing to the small diameter and angulation of the target vessel. The overall 30-day mortality rate was 2% (n = 3), and there were no differences in 30-day mortality in NPA (n = 2 [2%]) vs non-NPA (n = 1 [3%]; $P = 1.00$) and perioperative systemic complications in patients with NPA vs non-NPA (Table III). At 30 days, there were no endograft-related complications, and there were four (3%) bridging stent occlusions (n = 1 outer branch occlusion; n = 2 renal artery occlusions after FEVAR) or stenosis requiring reintervention (n = 1 stenosis of superior mesenteric artery outer branch), with all of these complications occurring in patients with NPA ($P = .302$). Three (2%) endoleaks (1 inner branch disconnection, 1 type Ic after FEVAR, and 1 type Ic after BEVAR) received an endovascular

Table II. Anatomical and procedural data of the 142 patients treated by fenestrated-branched endovascular aortic repair (F-BEVAR), stratified by presence of a narrow paravisceral aorta (*NPA*) (diameter <25 mm)

Characteristics	All patients (n = 142)			FEVAR (n = 85)			BEVAR (n = 57)		
	NPA (n = 95)	No NPA (n = 47)	*P* value	NPA (n = 73)	No NPA (n = 12)	*P* value	NPA (n = 22)	No NPA (n = 35)	*P* value
Anatomical data									
Aneurysm maximum diameter, mm	58 ± 11	62 ± 11	.127	56 ± 11	55 ± 11	.821	63 ± 11	63 ± 11	.905
Anatomical aneurysm classification			<.001[a]			<.001[a]			<.001[a]
PRA/JRA	73 (74)	12 (24)		60 (82)	5 (42)		13 (59)	7 (20)	
Extent IV	16 (16)	8 (17)		8 (11)	2 (17)		8 (36)	6 (17)	
Extent I-III	8 (8)	27 (57)		5 (7)	5 (42)		3 (25)	22 (63)	
Aortic dissection	5 (5)	1 (2)	.663	1 (1)	0 (0)	.99	4 (18)	1 (3)	.064
Minimum paravisceral aortic diameter, mm	20 ± 5	31 ± 5	<.001[a]	20 ± 5	27 ± 5	<.001[a]	21 ± 5	32 ± 5	<.001[a]
Aortic segment with NPA minimum diameter									
Zone 5	7 (7)	–		3 (4)	–		4 (18)	–	
Zone 6	18 (19)	–		11 (15)	–		7 (32)	–	
Zone 7	26 (27)	–		24 (32)	–		2 (9)	–	
Zone 8	44 (45)	–		35 (47)	–		9 (41)	–	
Longitudinal extension of NPA, mm	27 ± 18	–		31 ± 18	–		19 ± 18	–	
NPA focal extension	13 (14)	–		3 (4)	–		10 (45)	–	
Calcification of NPA									
Absent (<25%)	66 (67)	–		55 (65)	–		11 (50)	–	
Mild (25%-50%)	19 (20)	–		12 (16)	–		7 (32)	–	
Moderate/severe (>50%)	10 (11)	–		6 (8)	–		4 (18)	–	
Aortic thrombus of NPA									
Absent (<25%)	57 (60)	–		52 (71)	–		5 (23)	–	
Mild (25%-50%)	15 (15)	–		10 (14)	–		5 (23)	–	
Moderate/severe (>50%)	23 (24)	–		11 (15)	–		12 (55)	–	
NPA thrombus thickness, mm	9 ± 8	–		7 ± 8	–		13 ± 8	–	
Mean aortic angle of paravisceral aorta, °	26 ± 13	19 ± 13	.013[a]	24 ± 14	22 ± 13	.738	30 ± 14	18 ± 13	.003[a]
Aortic lumen CA level, mm	25 ± 6	34 ± 6	<.001[a]	24 ± 6	28 ± 6	.012[a]	26 ± 6	37 ± 6	<.001[a]
Aortic lumen SMA level, mm	23 ± 6	34 ± 7	<.001[a]	22 ± 7	29 ± 7	.025[a]	25 ± 7	36 ± 7	<.001[a]
Aortic lumen RRA level, mm	23 ± 6	32 ± 6	<.001[a]	22 ± 6	29 ± 6	.012[a]	24 ± 6	34 ± 6	<.001[a]
Aortic lumen LRA level, mm	22 ± 6	32 ± 6	<.001[a]	22 ± 6	28 ± 6	.014[a]	23 ± 6	34 ± 6	<.001[a]
Target vessel diameter, mm									
CA	7.4 ± 1.5	7.6 ± 1.6	.932	7.2 ± 1.3	7.5 ± 1.5	.868	7.5 ± 1.5	7.7 ± 1.8	.781
SMA	8.0 ± 1.8	8.1 ± 1.9	.865	7.8 ± 1.8	8.0 ± 1.9	.986	8.1 ± 1.9	8.3 ± 1.6	.644
RRA	6.5 ± 1.5	6.5 ± 1.6	.999	6.2 ± 1.5	6.3 ± 1.5	.99	6.7 ± 1.7	6.6 ± 1.9	.748
LRA	6.4 ± 1.5	6.5 ± 1.5	.99	6.4 ± 1.6	6.5 ± 1.6	.878	6.6 ± 1.6	6.5 ± 1.5	.788
Procedural data and metrics									
Endograft design			.001[a]			.99			.791
Off the shelf	11 (12)	16 (34)		0 (0)	0 (0)		11 (50)	16 (46)	
Custom made	84 (88)	31 (66)		73 (100)	12 (100)		11 (50)	19 (54)	

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Table II. Continued.

Characteristics	All patients (n = 142)			FEVAR (n = 85)			BEVAR (n = 57)		
	NPA (n = 95)	No NPA (n = 47)	*P* value	NPA (n = 73)	No NPA (n = 12)	*P* value	NPA (n = 22)	No NPA (n = 35)	*P* value
Type of directional branches									.001[a]
Outer branches	–	–		–	–		8 (36)	28 (80)	
Inner branches	–	–		–	–		14 (63)	7 (20)	
CA main bridging stent									
Balloon expandable	80 (84)	21 (45)	<.001[a]	44 (100)	12 (100)	.99	7 (33)	9 (26)	.577
Self-expandable	14 (15)	26 (55)		0 (0)	0 (0)		14 (66)	26 (74)	
Stent reinforcement	9 (9)	2 (43)	.338	1 (2)	0 (0)	.99	8 (38)	2 (6)	.009[a]
SMA main bridging stent									
Balloon expandable	74 (78)	13 (28)	<.001[a]	65 (100)	12 (100)	.99	1 (5)	1 (2)	.99
Self-expandable	21 (22)	34 (72)		0 (0)	0 (0)		21 (95)	34 (98)	
Stent reinforcement	17 (18)	9 (19)	.99	4 (6)	2 (17)	.198	13 (59)	7 (20)	<.001[a]
RRA main bridging stent									
Balloon expandable	76 (80)	12 (26)	<.001[a]	71 (100)	12 (100)	.99	3 (15)	0 (0)	.050
Self-expandable	17 (18)	33 (74)		0 (0)	0 (0)		17 (85)	33 (100)	
Stent reinforcement	19 (20)	19 (40)	.150	7 (9)	1 (8)	.99	12 (60)	18 (55)	.99
LRA main bridging stent									
Balloon expandable	74 (98)	14 (30)	<.001[a]	66 (100)	12 (100)	.99	1 (5)	2 (61)	.99
Self-expandable	19 (20)	31 (70)		0 (0)	0 (0)		19 (95)	31 (39)	
Stent reinforcement	17 (18)	18 (40)	.124	5 (75)	1 (8)	.99	12 (55)	17 (53)	.787
Total operating time, min	196 ± 120	238 ± 126	.056	141 ± 108	162 ± 115	.537	225 ± 161	240 ± 173	.744
Fluoroscopy time, min	92 ± 44	96 ± 51	.629	85 ± 35	90 ± 41	.655	122 ± 53	126 ± 48	.769
Radiation exposure, mGy	2134 ± 1463	2705 ± 1099	.019[a]	1989 ± 1397	2241 ± 1327	.561	2349 ± 1635	2902 ± 1639	.303
Contrast volume, mL	121 ± 70	148 ± 67	.029[a]	100 ± 55	132 ± 50	.062	157 ± 91	162 ± 78	.984

BEVAR, Branched endovascular aortic repair; *CA*, celiac artery; *FEVAR*, fenestrated endovascular aortic repair; *JRA*, juxtarenal artery; *LRA*, left renal artery; *PRA*, proximal renal artery; *RRA*, right renal artery; *SMA*, superior mesenteric artery.
Values are mean ± standard deviation or number (%).
[a]Statistically significant.

reintervention during the initial admission. The cumulative rate of early bridging stent complications was 8% in case of NPA and 0% in non-NPA ($P = .052$), and 30-day technical success rates were 92% and 100%, respectively ($P = .095$).

Midterm outcomes. The median follow-up was 24 months (range, 1-122 months); the overall survival at 4 years was 85% (95% confidence interval [CI], 80-92) and there were not aortic-related deaths. During follow-up, loss of patency had occurred in 11 target vessels (n = 4 FEVAR, n = 7 BEVAR; 8 occlusions and 3 reinterventions for stenosis) and a target vessel endoleak requiring reintervention had occurred in 24 target vessels (n = 18 FEVAR, n = 6 BEVAR). Kaplan-Meier estimated primary patency at 4 years was 95% (95% CI, 91-99) and freedom from target vessel endoleak-related reinterventions was 85% (95% CI, 79-92), resulting in an 82% (95% CI, 74-90) freedom from TVI. Comparing the celiac-mesenteric arteries with the renal arteries, freedom from TVI was 82% (95% CI, 72-93) vs 81% (95% CI, 68-96; $P = .700$), primary patency was 96% (95% CI, 90-100; n = 3 events) vs 94% (95% CI, 88-100, n = 8 events; $P = .350$), and freedom from target vessel endoleak was 86% (95% CI, 77-96, n = 9 events) vs 83% (95% CI, 73-98, n = 15 events; $P = .809$) respectively.

Freedom from TVI was 81% (95% CI, 75-95) in patients with a NPA and 80% (95% CI, 68-94) and in those without NPA ($P = .220$) (Fig 1, *A*). The result was maintained for both FEVAR (NPA, 81% [95% CI, 62-88]; non-NPA, 76% [95% CI, 60-99]; $P = .870$) (Fig 1, *B*) and BEVAR (NPA, 77% [95% CI, 69-99]; non-NPA, 80% [95% CI, 66-99]; $P = .100$) (Fig 1, *C*). In the NPA group, renal arteries had a lower primary patency both in FEVAR (91% [95% CI, 79-98] vs 97% [95% CI, 94-100]; $P = .040$) and BEVAR (82% [95% CI, 41-89] vs 97% [95% CI, 92-100]; $P = .001$) compared with celiac-mesenteric arteries.

After multivariate analysis (Table IV), NPA alone was not associated with freedom from TVI in FEVAR, using both a 25-mm (HR, 3.25; 95% CI, 0.55-32.69; $P = .164$) and a 20-

Table III. Early (30-day) outcomes of the 142 patients treated by fenestrated-branched endovascular aortic repair (F-BEVAR), stratified by presence of a narrow paravisceral aorta (*NPA*) (diameter <25 mm)

Characteristics	Overall (n = 142)			FEVAR (n = 85)			BEVAR (n = 57)		
	NPA (n = 95)	No NPA (n = 47)	*P* value	NPA (n = 73)	No NPA (n = 12)	*P* value	NPA (n = 22)	No NPA (n = 35)	*P* value
Systemic outcomes									
Death	2 (2)	1 (3)	.99	1 (2)	0 (0)	.99	1 (5)	1 (3)	.347
Myocardial infarction	2 (2)	0 (0)	.99	2 (3)	0 (0)	.99	0 (0)	0 (0)	.99
Respiratory failure	7 (8)	4 (8)	.481	5 (7)	0 (0)	.99	2 (9)	4 (11)	.666
Acute kidney insufficiency	6 (7)	3 (6)	.699	3 (4)	0 (0)	.99	3 (13)	3 (8)	.99
Gastrointestinal complications	3 (4)	0 (0)	.562	2 (3)	0 (0)	.99	1 (5)	0 (0)	.99
Stroke/TIA	0 (0)	2 (4)	.070	0 (0)	0 (0)	.99	0 (0)	2 (6)	.489
Spinal cord injury	4 (5)	1 (2)	.99	3 (4)	0 (0)	.99	1 (5)	1 (3)	.99
Surgical outcomes									
Procedural technical success	94 (99)	47 (100)	.99	73 (100)	12 (100)	.99	22 (100)	35 (100)	.99
Complications									
Endograft-related complications	0 (0)	0 (0)	.99	0 (0)	0 (0)	.99	0 (0)	0 (0)	.99
Target vessel occlusion/stenosis	4 (5)	0 (0)	.302	2 (3)	0 (0)	.99	2 (9)	0 (0)	.144
Reintervention for target vessel endoleak	3 (4)	0 (0)	.551	1 (2)	0 (0)	.99	2 (9)	0 (0)	.144
Vascular access complication	3 (4)	3 (6)	.99	1 (2)	0 (0)	.99	2 (9)	3 (8)	.99
30-Day technical success	7 (92)	47 (100)	.095	69 (95)	12 (100)	.99	19 (86)	35 (100)	.053

BEVAR, Branched endovascular aortic repair; *FEVAR*, fenestrated endovascular aortic repair; *TIA*, transient ischemic attack.
Values are number (%).

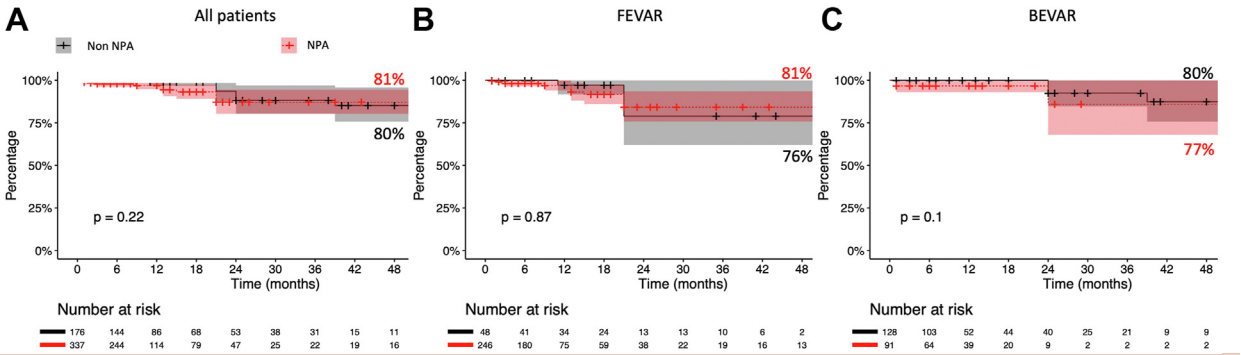

Fig 1. (A) Kaplan-Meier curve of freedom from target vessel instability (TVI) after fenestrated-branched endovascular aortic repair (F-BEVAR), stratified by presence of a narrow paravisceral aorta (NPA) < 25 mm in diameter. Standard error (SE) <10%. **(B)** Kaplan-Meier curve of freedom from TVI after fenestrated endovascular aortic repair (*FEVAR*), stratified by presence of a NPA of 25 mm in diameter. The SE was <10%. **(C)** Kaplan-Meier curve of freedom from TVI after BEVAR, stratified by presence of a NPA of <25 mm in diameter. SE <10%.

mm (HR, 2.81; 95% CI, 0.96-15.32; *P* = .088) cutoff (Supplementary Fig, online only). Aneurysm extent classification (HR, 1.64; 95% CI, 0.24-1.62; *P* = .348), NPA longitudinal extension (HR, 1.16; 95% CI, 0.44-3.38; *P* = .775), calcification (HR, 1.00; 95% CI, 0.39-2.53; *P* = .993), angulation (HR, 3.85; 95% CI, 0.87-45.1; *P* = .120), and type of bridging stent (HR, 0.98; 95% CI, 0.36-2.68; *P* = .783) were also not associated with fenestrations instability. The concomitant presence of an NPA of <20 mm and angulation of >30° was significantly associated with TVI in FEVAR (HR, 3.45; 95% CI, 1.09-36.99; *P* = .018) (Fig 2), being the result mostly driven by target vessel occlusion; all (n = 4) occurred in this subgroup of FEVAR patients. Also a longer bridging distance (HR, 1.23; 95% CI, 1.01-3.24; *P* = .031) and a smaller target vessel size (HR, 0.29; 95% CI, 0.17-0.67; *P* = .010) had a higher risk of TVI. The coexistence of an NPA of <20 mm and angulation of >30° was associated with TVI (HR, 3.50; 95% CI, 1.10-36.90; *P* = .015) also after exclusion of patients with aortic dissection (n = 1).

Table IV. Univariate and multivariate Cox proportional hazards for target vessel instability (TVI), stratified by type of target vessel incorporation

Characteristics	Univariate		Multivariate	
	HR (95% CI)	*P* value	HR (95% CI)	*P* value
FEVAR				
TAAA	1.64 (0.24-1.62)	.348	–	–
Aortic dissection	0.16 (0.09-6.57)	.545	–	–
NPA <20 mm	2.95 (0.99-8.52)	.054	2.81 (0.96-15.32)	.088
NPA longitudinal extension	1.16 (0.44-3.38)	.775	–	–
NPA severe calcification	1.00 (0.39-2.53)	.993	–	–
NPA thrombus thickness	0.76 (0.23-3.15)	.675	–	–
NPA angle >30°	3.24 (0.93-22.14)	.087	3.49 (0.81-59.31)	.342
NPA <20 mm + NPA angle >30°	–	–	3.21 (1.03-48.70)	.036[a]
NPA location in zone 8	3.00 (1.10-5.44)	.072	–	–
Gap distance	1.55 (1.22-1.75)	.001[a]	1.23 (1.01-3.24)	.031[a]
Renal artery	1.76 (0.55-5.59)	.336	–	–
Target artery diameter	0.23 (0.12-0.45)	.001[a]	0.29 (0.17-0.55)	.003[a]
Type of bridging stent, VBX	0.98 (0.36-2.68)	.783	–	–
BEVAR				
TAAA	0.91 (0.06-3.64)	.462	–	–
Aortic dissection	0.55 (0.12-12.83)	.664	–	–
Outer branch	1.09 (0.27-4.17)	.891	1.21 (0.14-6.53)	.942
NPA <25 mm	2.11 (0.80-3.45)	.897	2.02 (0.59-5.23)	.948
NPA longitudinal extension >25 mm	1.59 (0.99-12.13)	.053	2.00 (0.87-38.43)	.182
NPA severe calcification	1.69 (0.93-7.04)	.045[a]	1.31 (0.79-10.33)	.222
NPA location in zone 6	2.31 (0.99-17.22)	.052	–	–
NPA thrombus thickness	5.43 (3.41-56.4)	.542	–	–
NPA angle >30°	1.02 (0.94-1.18)	.602	–	–
Self-expanding bridging stent	0.91 (0.22-5.67)	.623	–	–
Bridging stent reinforcement	0.87 (0.89-3.14)	.563	–	–
Outer branch + NPA longitudinal extension >25 mm	–	–	3.02 (1.01-36.33)	.040[a]
Outer branch + NPA severe calcification	–	–	1.70 (1.00-22.42)	.048[a]
Gap distance	1.08 (0.89-1.35)	.103	–	–
Renal artery	1.68 (0.42-3.01)	.235	–	–
Target artery diameter	0.23 (0.12-0.45)	.001[a]	0.31 (0.20-0.71)	.006[a]

BEVAR, Branched endovascular aortic repair; *CI*, confidence interal; *FEVAR*, fenestrated endovascular aortic repair; *HR*, hazard ratio; *NPA*, narrow paravisceral aorta; *VBX*, Viabahn balloon expandable stent graft.
[a]Statistically significant.

In BEVAR, TVI was not associated with an NPA diameter of <25 mm (HR, 2.11; 95% CI, 0.80-3.45; $P = .897$), NPA thrombus thickness (HR, 5.43; 95% CI, 3.41-56.4; $P = .542$), angle (HR, 1.02; 95% CI, 0.94-1.18; $P = .602$), or type of bridging stent (HR, 0.91; 95% CI, 0.22-5.67; $P = .623$). After multivariate analysis, the use of outer branches in case of an NPA longitudinal extension of >25 mm (HR, 3.02; 95% CI, 1.01-36.33; $P = .040$) and NPA severe calcification (HR, 1.70; 95% CI, 1.00-22.42; $P = .048$) were associated with a higher chance for TVI (Fig 3), as well as a smaller target artery diameter (HR, 0.31; 95% CI, 0.20-0.71; $P = .006$). After exclusion of patients with aortic dissection (n = 5), outer branches in an NPA longitudinal extension of >25 mm (HR, 2.62; 95% CI, 1.01-25.12; $P = .044$) and NPA severe calcification (HR, 1.57; 95% CI, 1.00-31.66; $P = .046$) were still associated with TVI.

DISCUSSION

The definition of narrow aorta by itself is not well-established. In the modern endovascular era, the increasing number of different available endografts for the treatment of JRAA/PRAA and TAAA has allowed operators to push the treatment toward cases with increasingly complex anatomies. In this scenario, a narrow aorta is primarily defined in relation to the minimum

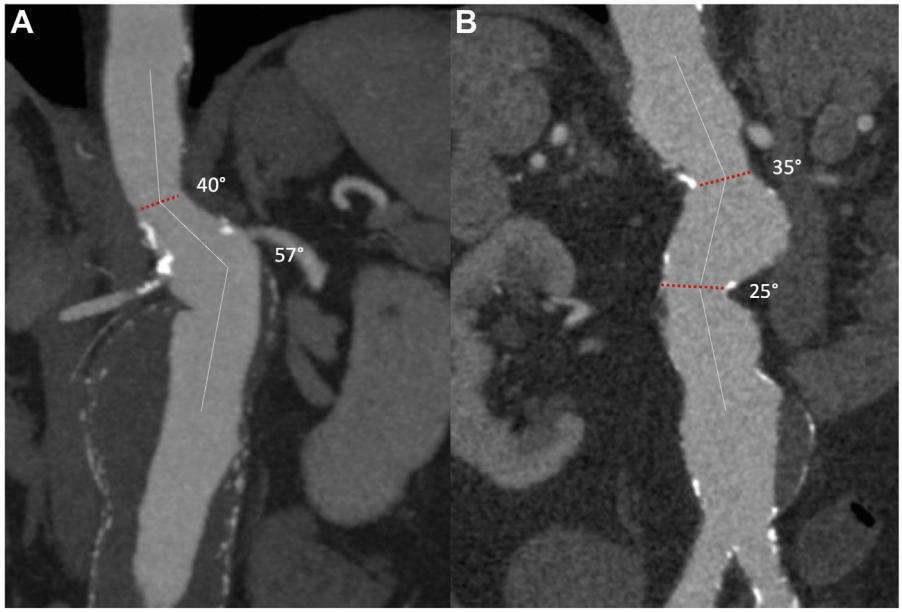

Fig 2. (A) Computed tomography angiography (CTA) multiplanar reconstruction of a pararenal aortic aneurysms (PRAA) with a narrow paravisceral aorta (NPA) (red dotted line) associated with aortic angulation of >30° (white solid line). **(B)** CTA multiplanar reconstruction of a PRAA with a multifocal NPA (red dotted line) associated with aortic angulation of >30° (white solid line).

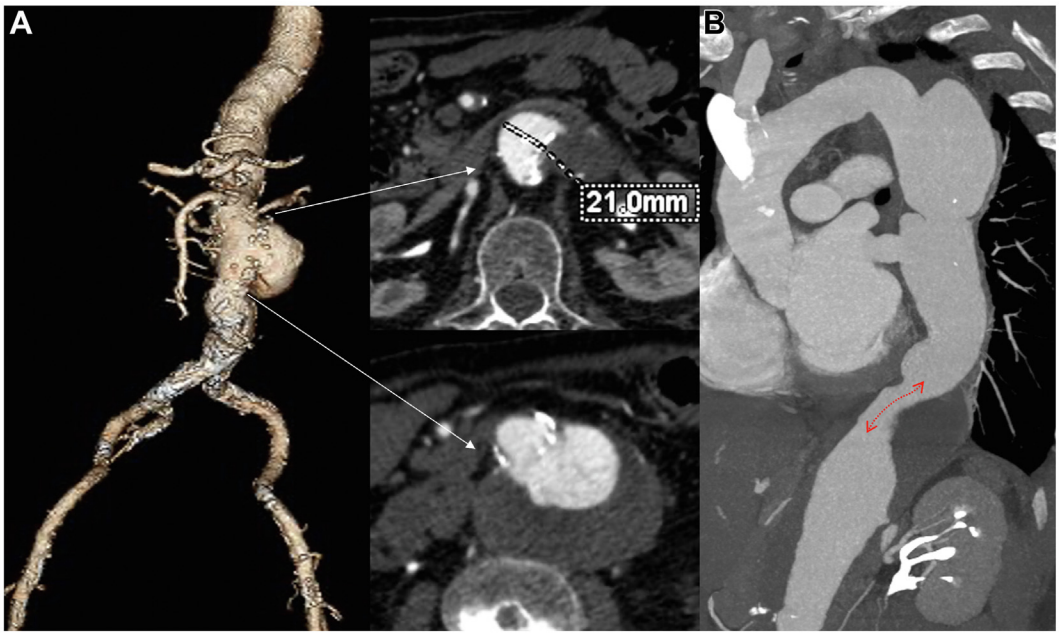

Fig 3. (A) Computed tomography angiography (CTA) three-dimensional reconstruction of a thoracoabdominal aortic aneurysm (TAAA) with a narrow paravisceral aorta (NPA) associated with severe aortic wall calcifications. **(B)** CTA multiplanar reconstruction of a TAAA with a NPA extended for >25 mm (red arrow).

diameter that is necessary for the safe implantation of fenestrated and/or branched grafts and subsequent bridging of the target vessels with covered stents.

This particular anatomical situation is gaining attention, especially with branched endografts, because of the need for a minimum space for adequate cuff opening in case of outer conformation, whereas it is less evident in fenestrated grafts, where the fenestration is generally customized to fit the aortic wall at the level of the ostium of the target vessel. For these reasons, the inner branch technology has been developed with the objective to allow for adequate cuff position inside the main graft

with no risk of compression in case of narrow aortic zones. However, the manufacturing companies do not specify by the instructions for use of a minimum diameter for endograft implantation, and the limit is established for the two off-the-shelf branch devices available on the market based on feasibility studies, specifically of 24 mm for the inner branched (E-nside, Artivion) and 25 mm for the outer branched (T-branch, Cook).[8,9]

In our experience with NPA alone, intended as an inner-inner wall diameter of <25 mm, this factor was not cause of limited technical success or TVI for either FEVAR or BEVAR. However, it is interesting to note that all early target vessel complications occurred in patients with an NPA, suggesting that, although feasible and safe, fenestrated-BEVAR (F-BEVAR) in NPA still represents a more challenging situation, especially if associated with other anatomical characteristics.

Regarding BEVAR, the presence of an NPA alone did not impact on technical success, either in the outer or inner branches, clarifying the finding that, in these complex anatomies, the procedure is technically feasible with a low risk of target vessel complications in the early poatprocedure period. This result is in line with the findings of Ferrer et al,[7] who reported no differences in technical success and reintervention rate in 48 patients undergoing BEVAR with the off-the-shelf outer branched Cook T-branch device between large and narrow lumen (<25 mm). They also did not found NPA by itself causing decreased patency over time, and this is similar to our findings of no direct effect of NPA on TVI.

The lack of a significant impact of NPA on clinical outcomes may be related to the fact that the measure of a narrow aortic lumen is often done by evaluating the inner-inner diameter. This factor is a simple geometrical measure, but anatomically there may be some additional space that can be obtained, depending on the wall quality. A narrow true lumen in a dissection, or a narrow aorta because of aortic wall plaques primarily composed of soft thrombus, may subsequently gain some additional space once the endograft is in place and the bridging components have been adequately expanded after ballooning. This situation contrast with the reason why we found that a NPA with calcified wall has an higher rate of TVI for outer branches in comparison with inner conformation, because of a lack of space for the main graft and branch adaptation. Similarly Abisi et al[16] reported a 100% technical success rate and 100% 12-month patency rate in their preliminary clinical experience using a custom inner branch device in 14 patients with a narrow aorta (<24 mm).

Comparing outer with inner branches, another aspect that showed a significant impact on TVI was a longitudinal extension of >25 mm. This result may be related to multiple branches coexisting together in a small area in some segment. In this setting, the inner branch conformation may be helpful not only in facilitating adequate cuff opening, but also in avoiding competition between multiple branches and the main endograft.

NPA by itself is not a limitation for FEVAR. In general, the fenestrated endograft can be customized down to 18 to 22 mm in diameter in the narrowest part, and does not need additional space because the fenestrations are apposed to the aortic wall and a short bridging stent is needed to align the fenestration with the ostium of the vessel and guarantee adequate long-term sealing.

Overall in FEVAR, the vast majority of TVIs reported in most large series[17-19] are driven by endoleaks; stent occlusions are infrequent. Also in this experience, most target vessel events in FEVAR were endoleaks. However, when analyzing the relation between NPA and TVI, all occlusions were aggregated in cases with a NPA. In particular stent occlusion occurred in all cases with a NPA of <20 mm in association with any type of aortic angulation of >30°. Of the four events reported, all were related to inadequate bridging stent conformation (3 compression of the fenestration and 1 inadequate flare). This result may be explained by the fact that this particular condition, generally rare, may be particular risky for adequate stent alignment or main graft correct expansion at the level of the target fenestration, thus increasing the risk of stent occlusion in the mid term. The angulation as negative predicting factor of TVI in F-BEVAR was already described by Squizzato et al.[10] The results of our analysis point out that the association of these two complex anatomical issues—narrow aorta and angulation—may have an amplified negative effect, specifically causing bridging stent occlusion.

Our findings may help the operator during the planning phase to decrease the risks of TVI related to a narrow aorta. In particular for BEVAR, we aim for a dedicated custom plan that takes into consideration these anatomical features with a general preference for an inner conformation, and perform an intraoperative branches technical assessment by intravascular ultrasound examination.[20] In FEVAR, in the case of NPA, we currently perform a routinary accurate intraoperative and postoperative[13] geometrical quality control of the implants by cone-beam CT scan or CTA. During endovascular planning, it should be considered that an excessive aortic diameter may represent an unfavorable scenario in FEVAR, being associated with an excessive gap distance between the fenestration and the target vessel.[13,18,21] A 20- to 35-mm paravisceral aorta diameter may be ideal to avoid complications related to both a narrow aorta and a long bridging distance, but this result may be influenced by aortic graft size and the reciprocal distance between the target vessels as well. Further studies are needed to assess the optimal strategy in cases of a narrow or large paravisceral aorta.

This study has some limitations that are worthy of mention. It is a retrospective, single-center study with a limited number of cases and a low number of adverse

events. Outcomes may have been influenced by operator preference during the planning phase and graft choice (branched rather that fenestrated, off-the-shelf rather that a custom device, type of bridging stent) based on narrow aorta location, quality, and extension. The limited number of patients and events may have led to a type II error, and an NPA may be associated with worsened outcomes in larger series. The assessment of the impact of type of bridging stent on TVI was limited by the use of multiple types of stent, mostly self-expanding stents in BEVAR and VBX stents in FEVAR. Also postoperative medical therapy may have an impact on target vessel patency, but compliance with medications during follow-up was not known; clopidogrel resistance was not routinely assessed. The study is strengthened by the detailed and reproducible extensive anatomical analysis of parameters at the pre- and post-CTAs, which allows for an accurate and precise outcomes evaluation.

CONCLUSIONS

FEVAR and BEVAR are both feasible in NPA, and overall provide satisfactory target vessel durability. The use of outer branches should be carefully evaluated in cases where an NPA of <25 mm in diameter is present, in conjunction with a longitudinal extension >2.5 cm or moderate to severe calcifications. In FEVAR, bridging stent patency may be negatively influenced by an NPA of <20 mm in association with any type of aortic angulation of $>30°$. Planning, implantation, and follow-ups protocol for F-BEVAR need to take into account these particular aortic anatomical conditions, to ensure long-term target vessel stability.

AUTHOR CONTRIBUTIONS

Conception and design: MP, FS, FG, MA
Analysis and interpretation: MP, FS, MA
Data collection: EF, MB, EC
Writing the article: MP, FS
Critical revision of the article: MP, FS, EF, MB, EC, FG, MA
Final approval of the article: MP, FS, EF, MB, EC, FG, MA
Statistical analysis: FS
Obtained funding: Not applicable
Overall responsibility: MP

DISCLOSURES

None.

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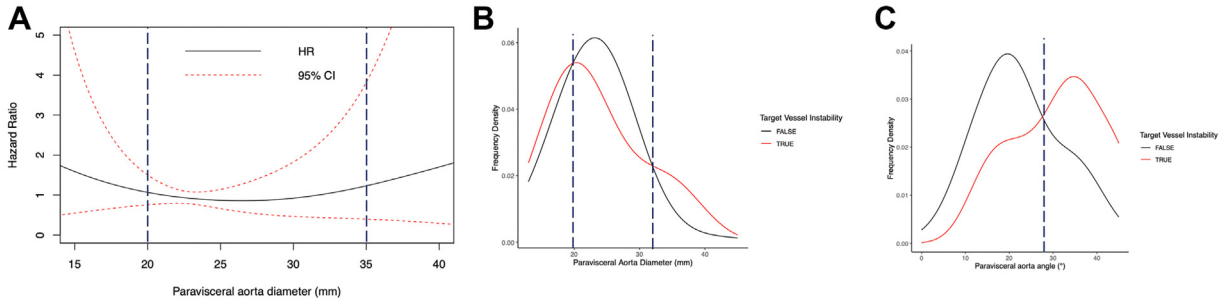

Supplementary Fig (online only). **(A)** Penalized splines function of hazard ratios (*HRs*)for target vessel instability (TVI) versus minimum diameter of the paravisceral aorta in patients treated by fenestrated endovascular aortic repair (FEVAR). To note the mild U-shaped curve with increased HR for TVI for aortic diameter values of <20 mm or >35 mm. **(B)** Frequency density distribution of the diameter of the paravisceral aorta, stratified by occurrence of TVI during follow-up. To note the intersection of the curves at approximately 20 mm and 35 mm. **(C)** Frequency density distribution of the angle of the paravisceral aorta, stratified by the occurrence of TVI during follow-up. To note the intersection of the curves at approximately 30°, indicating a higher chance for target vessels instability (TVI) in case of aortic angulation >30°. *CI*, confidence interval.