Effect of celiac axis compression on target vessel-related outcomes during fenestrated-branched endovascular aortic repair

Francesco Squizzato, MD, Gustavo S. Oderich, MD, Emanuel R. Tenorio, MD, PhD, Bernardo C. Mendes, MD, *and* Randall R. DeMartino, MD, MS, *Rochester, Minn*

ABSTRACT

Objective: To report the effect of median arcuate ligament (MAL) compression on outcomes and technical aspects of celiac artery (CA) stenting during fenestrated-branched endovascular aneurysm repair for thoracoabdominal aortic aneurysms (TAAA) or pararenal aortic aneurysms.

Methods: We retrospectively reviewed the clinical and anatomic data on 300 consecutive patients enrolled in a prospective nonrandomized physician-sponsored investigational device exemption study from 2013 to 2018. From this group, 230 patients with CA incorporation by fenestration or directional branch were included. MAL compression was defined by preoperative computed tomography angiogram as a J-hook narrowing of the proximal CA at the level of the ligament; the shift angle between the downward and upward segments within the CA was measured. End points were technical success, rates of intraoperative or early (30-days) CA branch revision, and freedom from target vessel instability, defined by any death or rupture owing to target vessel complication, occlusion, or reintervention for stenosis, endoleak, or disconnection.

Results: CA incorporation was performed using fenestrations in 118 patients (51%) and directional branches in 112 (49%). MAL compression was present in 97 patients (42%), resulting in a stenosis of more than 50% in 48 (49%). MAL compression was more often present in patients with extent I to III TAAAs compared with extent IV TAAA-pararenal aortic aneurysms (56% vs 31%; $P < .001$). Technical success rate was 99%. Patients with MAL compression more often received a directional branch (65% vs 37%; $P < .001$), self-expanding bridging stent grafts (32% vs 16%; $P = .007$), adjunctive bare metal stents (46% vs 24%; $P = .001$), and coverage of the gastric artery (44% vs 22%; $P < .001$). An intraoperative ($n = 6$, 2.6%) or early ($n = 1$, 0.4%) revision of the CA branch was required in seven patients (3%) owing to dissection/occlusion ($n = 2$ [0.9%]), kinking/stenosis ($n = 3$ [1.3%]), stent dislodgement ($n = 1$ [0.4%]), or type IC endoleak ($n = 1$ [0.4%]). A shift angle of less than 120° was the most significant factor associated with CA branch revision (odds ratio, 10.9; 95% confidence interval, 2.3-88.9; $P = .013$). Freedom from CA branch instability was 97 ± 2% at 4 years, and this outcome was not associated with MAL compression (hazard ratio, 0.83; 95% confidence interval, 0.14-5.02; $P = .588$) or any other predictor.

Conclusions: MAL compression was more common in extent I to III TAAAs, and related to additional challenges for CA stenting in fenestrated-branched endovascular aneurysm repair. This process may include bare metal stenting, gastric artery coverage, or early revision, especially in presence of an angulation of less than 120°. However, durable results can be achieved for CA incorporation despite these difficulties. (J Vasc Surg 2021;73:1167-77.)

Keywords: Fenestrated and branched endovascular aortic repair; Thoracoabdominal aortic aneurysm; Pararenal aortic aneurysm; Celiac artery; Median arcuate ligament syndrome; Aortic aneurysm

Endovascular aneurysm repair with fenestrated or branched endografts (F-BEVAR) represents a valid option for the treatment of pararenal aortic aneurysms (PRAA) or thoracoabdominal aortic aneurysms (TAAA).[1-3] F-BEVAR graft design implies the incorporation of aortic side vessels using fenestrations, directional branches, or scallops. Successful catheterization and stenting with a bridging stent-graft of each targeted vessel is required to optimize sealing and vessel alignment. Previous reports on F-BEVAR have demonstrated excellent branch-related outcomes in terms of safety, technical success, patency rates, and freedom from aneurysm-related death[1-4]; however, the increasing tendency to use supraceliac landing zones[1] may impose additional challenges for the celiac artery (CA).[5,6]

Incorporation of the CA may be compromised by compression by the median arcuate ligament (MAL), which occurs in up to 20% to 30% of patients in the

From the Division of Vascular and Endovascular Surgery, Mayo Clinic.

Author conflict of interest: G.S.O. has received consulting fees and grants from Cook Medical, W. L. Gore & Associates, and GE Healthcare (all paid to Mayo Clinic with no personal income).

Additional material for this article may be found online at www.jvascsurg.org.

Correspondence: Randall R. DeMartino, MD, MS, Associate Professor of Surgery, Mayo Clinic, Division of Vascular and Endovascular Surgery, Department of Surgery, 200 First St SW, 55905 Rochester, MN (e-mail: demartino.randall@mayo.edu).

The editors and reviewers of this article have no relevant financial relationships to disclose per the JVS policy that requires reviewers to decline review of any manuscript for which they may have a conflict of interest.

0741-5214

https://doi.org/10.1016/j.jvs.2020.07.092

general population. This fibrous arch unites the diaphragmatic crura on either side of the aortic hiatus.[7] Even if asymptomatic, this compression may cause stenosis and steep angulation of the vessel, resulting in more difficult catheterization and stent placement, as well as kinking, dislodgement, or fracture of the bridging stent during follow-up. The aim of this study was to assess the prevalence of MAL compression of the CA among patients with PRAA or TAAA undergoing F-BEVAR, its anatomic characteristics in terms of angulation and grade of stenosis, and the impact of MAL compression on early and mid-term outcomes of F-BEVAR.

METHODS

All patients were prospectively enrolled in a nonrandomized investigational device exemption study on F-BEVAR (NCT1937949 and NCT2089607). Patients consented to participation in the device study and additional data collection; analysis of the present study was approved by the Mayo Clinic Institutional Review Board. Additional consenting for this retrospective review was waived.

A retrospective review of prospectively collected data was performed on 300 consecutive patients operated from 2013 and 2018. Only patients requiring CA incorporation through a fenestration or directional branch were included in the study. Patients were excluded if the CA was chronically occluded or incorporation was done using a scallop.

Demographics, clinical characteristics, cardiovascular risk factors, and operative and postoperative variables were prospectively collected.[8] Aneurysm classification was based on the Crawford classification, and evaluated by computed tomography angiography (CTA). Early postoperative period was defined as occurring within the first 30 days or within the hospital stay if longer than 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 CTA or CT without contrast and duplex ultrasound of the renal-mesenteric arteries.

MAL compression. The presence of MAL compression was evaluated at the preoperative CTA using sagittal multiplanar reconstructions. The Aquarius iNtuition software (v 4.4.13; TeraRecon, Foster City, Calif) was used for the assessment. No preoperative dynamic studies were performed. MAL compression was defined as a J-hook narrowing of the CA at the level of the ligament; a J-hook appearance alone, without any grade of stenosis, was not considered as a sign of MAL compression.[9] The severity was qualified in three grades on axial CTA images, according to the classification proposed by Sugae et al,[10] that was purposely adapted considering the presence of a non-normal (dilated) aorta. In particular, MAL was gauged as grade A in case of stenosis of less than 50% and stenosis length of 3 mm or less; grade B in case of between 50% and 80% stenosis with a 3- to 8-mm length; and grade C in case of stenosis of more than 80% and length of more than 8 mm. The grade of stenosis was measured at the level of the maximum degree of stenosis, which usually is located at the level of the MAL for MAL compression and at the CA ostium for atherosclerotic disease. The angle of emergence (AE) was measured on parasagittal three-dimensional reconstructions, and was defined as the angle between the vector of the first tract of the CA and the tangent to the aortic centerline at the level of the CA takeoff (Fig 1, *A*).[9] The shift angle (SA) was defined as the angle between the first tract of the CA (usually downward oriented) and the shifting of the CA at the level of the ligament (usually upward or horizontally oriented)[9] (Fig 1, *B*).

Device design. F-BEVAR was performed using manufactured patient-specific or off-the-shelf (t-branch) endografts based on the Cook Zenith Fenestrated platform (Cook Medical Inc, Brisbane, Australia). Endovascular planning and sizing was performed by one operator (G.S.O.). A proximal sealing zone of at least 25 mm was selected in normal supra-celiac aortic segments, defined by parallel aortic wall with no evidence of thrombus, calcium, or diameter enlargement of greater

ARTICLE HIGHLIGHTS

- **Type of Research:** Single-center, retrospective study of prospectively collected data
- **Key Findings:** In 300 patients celiac artery (CA) compression by the median arcuate ligament (MAL) was more often present in patients with extent I to III vs IV thoracoabdominal aneurysms (61% vs 39%; $P < .001$). Patients with extent I to III disease more often received a directional branch (65% vs 37%; $P < .001$), adjunctive bare metal stents (46% vs 24%; $P = .001$), coverage of the gastric artery (44% vs 22%; $P < .001$). A steep angulation <120° of the celiac axis was the most significant factor associated with CA branch revision (odds ratio, 10.9; 95% confidence interval, 2.3-88.9; $P = .013$). Freedom from CA branch instability was 97 ± 2% at 4 years, and this was not associated with celiac compression (hazard ratio, 1.17; 95% confidence interval, 0.14-5.12; $P = .900$).
- **Take Home Message:** MAL compression of the CA imposes additional challenges for stenting in fenestrated-branched endovascular aortic repair; an angulation of less than 120° was associated with branch revision. However, excellent midterm results can be achieved, and these are not affected by MAL compression.

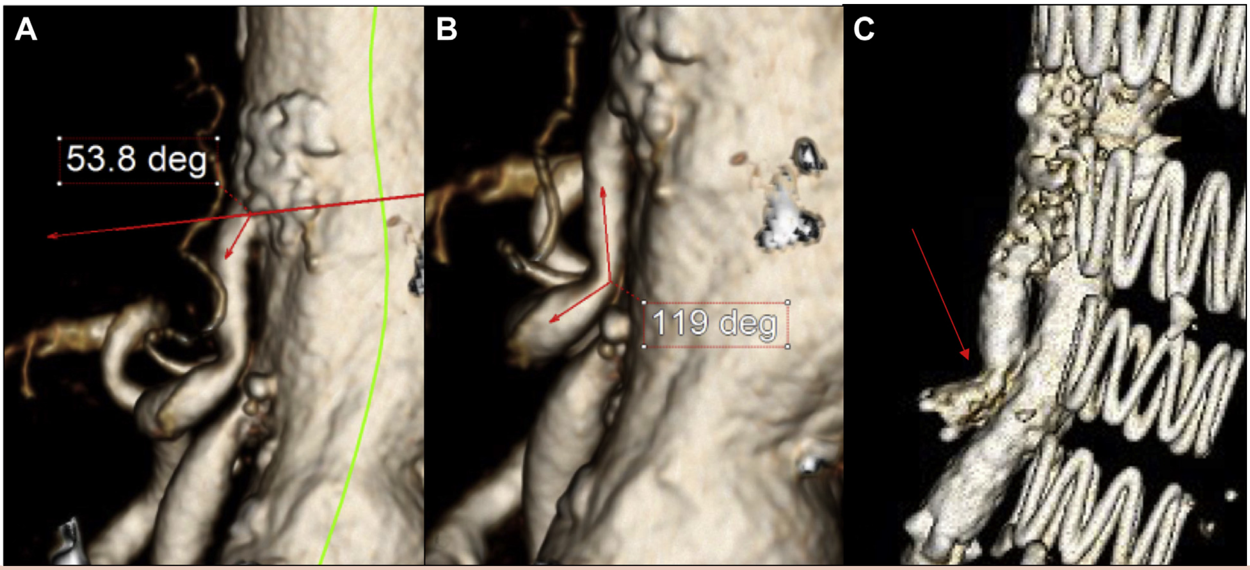


Fig 1. A, Three-dimensional preoperative computed tomography angiography (CTA) reconstruction showing the measurement of the shift angle (SA) in a patient with a pararenal aortic aneurysm. **B,** Measurement of the angle of emergence (AE) of the celiac artery (CA). **C,** Postoperative CTA of the same patient, showing kink of the stent at the level of the median arcuate ligament (MAL) (*red arrow*).

than 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 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. For the CA, the choice between fenestration and branch was not influenced by the presence of MAL compression.

Target vessel stenting. CA catheterization and stenting was usually performed through 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 (Viabahn, W. L. Gore & Associates, Flagstaff, Ariz; Fluency, C. R. Bard, Inc, Tempe, Ariz; or Flair endovascular stent-graft, C. R. Bard, Inc, Tempe, Ariz) or balloon-expandable (Viabahn balloon expandable VBX, W. L. Gore and Associates) covered stents. The cuff segment was often reinforced with a short balloon-expandable stent to prevent separation in case of self-expanding bridging stents.

In all cases, the distal landing of the bridging stent was deployed in a relatively straight portion of the target vessel, with a sealing length of 10 to 15 mm. In case of CA angulation caused by MAL compression, the distal edge was deployed before the SA if a sufficient length was present; otherwise, stenting was extended distal to the SA. 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. Coverage of the gastric artery was sometimes required. In the case of early CA bifurcation, stenting was sometimes extended into the splenic or hepatic artery with a bare metal stent to improve distal attachment. Postoperative medical therapy consisted in aspirin perioperatively and lifelong. Clopidogrel was reserved for patients receiving renal branches, starting 2 weeks after the procedure.

Technical assessment. Technical assessment of the stented CA included position, integrity, patency, and presence of endoleak. Details of the technical assessment protocol are provided elsewhere.[11,12] In summary, a selective digital subtraction angiography (DSA) was performed after CA stenting. A final completion DSA on anteroposterior view was used to assess the overall final technical result after complete deployment of all the endograft components. Finally a completion cone beam CT (CBCT) scan was performed without and with the use of contrast (Fig 1, *C*). The indication for immediate technical revision was left to the discretion of the primary operating surgeon. In general, treatment was recommended for type I or type III endoleak and for flow-limiting stent compressions, kinks, stenosis, dissection, or thrombus.

A CTA scan was obtained before discharge for all patients. Type III endoleaks not associated with side branch compression were typically observed for 2 to 6 months and revised if persistent and associated with sac enlargement. Type IA endoleak, severe side branch compression, or flow-limiting dissection were considered for postoperative revision before dismissal.

Any additional stenting or ballooning of the CA dictated by the intraoperative DSA or CBCT findings was defined as intraoperative revision. Revisions dictated by the CTA performed before discharge and performed in the early postoperative period were defined as early revisions.

Statistical analysis. Clinical and anatomic data, perioperative data, and outcomes were compared between patients with MAL compression vs patients without MAL compression, stratified by aneurysm extent (PRAA, type IV, type I-III TAAAs). The Society for Vascular Surgery reporting standards were used to define technical success and endoleak.[13,14] Major adverse events 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 or reintubation, paraplegia, stroke, bowel ischemia requiring surgical resection or intensive medical care, and estimated blood loss or more than 1 L. Spinal cord ischemia was classified according to the current reporting standards.[14] 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. Branch instability was defined as any branch-related death, rupture, occlusion, or reintervention for stenosis, kink, endoleak, or disconnection.

Results were reported as a number and percentage for categorical variables and mean ± standard deviation for continuous variables. The Pearson χ^2 or Fisher exact tests were used for analysis of categorical variables. Differences between means were tested with two-sided Student *t*-test or Wilcoxon rank-sum test as appropriate. A *P* value of less than .05 was used to determine statistical significance. Time-dependent outcomes were reported using Kaplan-Meier estimates; differences were determined by the log-rank test. Univariate logistic regression and Cox proportional hazards were used to identify procedural and anatomic predictors of early and late outcomes, respectively. An analysis of frequency density distribution of the value of the SA, stratified by necessity to perform an early revision of the CA, was used to determine the optimal SA cutoff associated with early CA revision (Supplementary Fig, online only).

RESULTS

Patients. CA incorporation was required in 281 of 300 consecutive patients; in 13 cases it was not incorporated due to a preoperative occlusion; a double-wide scallop without stenting of the CA was adopted in 51 cases that were therefore excluded from the analysis, leading to 230 patients.

Demographics and risk factors are shown in Table I. Most patients were male (n = 169 [74%]) and mean age was 74 ± 8 years; the most represented risk factors were smoking (n = 195 [85%]), hypertension (n = 208 [90%]), and hyperlipidemia (n = 193 [84%]).

Celiac compression characteristics. Overall, 97 patients (42%) had preoperative signs of MAL compression. This compression was classified as grade A in 49 cases (51%), grade B in 30 (31%), and grade C in 18 (19%). MAL compression was correlated with older age (75.4 ± 7.4 years vs 73.2 ± 7.6 years; *P* = .028), larger aneurysm diameter (68 ± 13 mm vs 65 ± 11 mm; *P* < .001), and aneurysm extent, being MAL compression more often present in extent I to III TAAAs compared with extent IV PRAAs (61% vs 39%; *P* < .001); aneurysm extent was also associated with MAL compression severity (Fig 2; *P* < .001). Regarding CA anatomic characteristics (Table II), a more downward-oriented AE (27 ± 16° vs 46 ± 21°; *P* < .001) and a steeper SA (114 ± 29° vs 158 ± 29°; *P* < .001) was observed in the presence of MAL compression. The mean length of a straight CA before the SA was 13.7 ± 5.7 mm, 14 ± 5.8 mm in case of MAL compression, and 13.4 ± 5.8 mm in case of no MAL compression (*P* = .511). A preoperative CA stenosis of more than 50% was present in 67 cases (29%) and was more likely to be caused by MAL compression than atherosclerosis (73% vs 27%; *P* < .001), as was a poststenotic ectasia of more than 11 mm (21.0% vs 2.3%; *P* < .001).

Among the 51 celiac arteries incorporated through a scallop, MAL compression was present in 13 (25%), and was classified as grade A in 11 (22%) and grade C in 2 (4%). The mean SA in these patients was 116 ± 28° for those with MAL compression and 153 ± 33° for those without MAL compression, and this finding was similar to patients receiving a branch or fenestration (*P* = .815 and *P* = .365, respectively). After inclusion of these 51 patients, MAL compression was still more frequent in extent I to III TAAA compared with extent IV PRAA (57% vs 39%; *P* < .001).

Stent graft and procedural details. Overall, patients with MAL compression more often received an off-the-shelf device (20% vs 8%; *P* = .008), a CA directional branch (65% vs 37%; *P* < .001), and a self-expanding bridging stent graft (32% vs 16%; *P* = .007), but these differences were removed after stratification by aneurysm extent (Table III).

Endovascular surgery duration (182 ± 64 minutes vs 160 ± 59 minutes; *P* < .001), fluoroscopy time (91 ± 34 minutes vs 81 ± 30 minutes; *P* = .012), and radiation dose (cumulative air kerma, 2526 ± 1995 mGy vs 2179 ± 1705 mGy; *P* < .001) were significantly higher

Table I. Demographics, cardiovascular risk factors, and anatomic characteristics of the 230 patients with pararenal aortic aneurysm (*PRAA*) or thoracoabdominal aortic aneurysm (*TAAA*) treated with fenestrated-branched endovascular aortic repair (F-BEVAR) requiring stenting of the celiac artery (CA)

Variable	Overall			PRAA			Extent IV			Extent I-III		
	MAL− (n = 133)	MAL+ (n = 97)	*P* value	MAL− (n = 29)	MAL+ (n = 19)	*P* value	MAL− (n = 57)	MAL+ (n = 19)	*P* value	MAL− (n = 47)	MAL+ (n = 59)	*P* value
Demographics												
Male sex	97 (72.9)	72 (74.2)	.945	24 (82.8)	15 (78.9)	.999	46 (80.7)	16 (84.2)	.999	27 (57.4)	41 (69.5)	.280
Age, years	73.2 ± 7.6	75.4 ± 7.4	.028[a]	74.2 ± 7.6	78.5 ± 6.1	.044[a]	74.4 ± 7.46	73.8 ± 7.6	.785	71.1 ± 7.5	74.9 ± 7.5	.011[a]
Age >80	24 (18.0)	30 (30.9)	.034[a]	6 (20.7)	7 (36.8)	.368	14 (24.6)	3 (15.8)	.634	4 (8.5)	20 (33.9)	.004[a]
Cardiovascular risk factors												
Smoking	114 (85.7)	81 (83.5)	.784	27 (93.1)	16 (84.2)	.615	48 (84.2)	15 (78.9)	.860	39 (83.0)	50 (84.7)	.999
Hypertension	117 (88.0)	91 (93.8)	.207	25 (86.2)	16 (84.2)	.999	48 (84.2)	19 (100.0)	.151	44 (93.6)	56 (94.9)	.999
Hyperlipidemia	110 (82.7)	83 (85.6)	.688	23 (79.3)	16 (84.2)	.962	47 (82.5)	18 (94.7)	.347	40 (85.1)	49 (83.1)	.984
BMI, kg/m^2	28.4 ± 5.3	28.0 ± 5.3	.573	28.6 ± 4.6	27.2 ± 4.4	.302	29.2 ± 5.7	29.1 ± 6.6	.957	27.3 ± 5.3	27.4 ± 5.1	.590
CAD	63 (47.4)	52 (53.6)	.423	11 (37.9)	12 (63.2)	.157	31 (54.4)	12 (63.2)	.689	21 (44.7)	28 (47.5)	.929
COPD	42 (31.6)	36 (37.1)	.463	9 (31.0)	6 (31.6)	.999	13 (22.8)	8 (42.1)	.183	20 (42.6)	22 (37.3)	.726
DM	19 (14.3)	14 (14.4)	.999	6 (20.7)	2 (10.5)	.598	7 (12.3)	5 (26.3)	.276	6 (12.8)	7 (11.9)	.999
CHF	16 (12.0)	10 (10.3)	.844	2 (6.9)	2 (10.5)	.999	6 (10.5)	4 (21.1)	.433	8 (17.0)	4 (6.8)	.179
Stroke/TIA	12 (9.0)	13 (13.4)	.401	1 (3.4)	3 (15.8)	.328	7 (12.3)	0 (0.0)	.252	4 (8.5)	10 (16.9)	.324
PAD	24 (18.)	19 (16.6)	.864	2 (6.9)	3 (15.8)	.615	11 (19.3)	7 (36.8)	.213	11 (23.4)	9 (15.3)	.415
CKD	59 (44.4)	45 (46.4)	.789	13 (44.8)	10 (52.6)	.815	28 (49.1)	7 (36.8)	.506	18 (38.3)	28 (47.5)	.454
Dialysis	0 (0)	1 (1.0)	.422	29 (100.0)	19 (100.0)	—	57 (100.0)	19 (100.0)	—	0 (0.0)	1 (1.7)	.999

BMI, Body mass index; *CAD*, coronary artery disease; *CHF*, congestive heart failure; *COPD*, chronic obstructive pulmonary disease; *CKD*, chronic kidney disease; *DM*, diabetes mellitus; *MAL+*, presence of celiac artery compression by the median arcuate ligament; *MAL−*, absence of celiac artery compression; *TIA*, transient ischemic attack.
Values are mean ± standard deviation or number (%).
[a]Statistically significant.

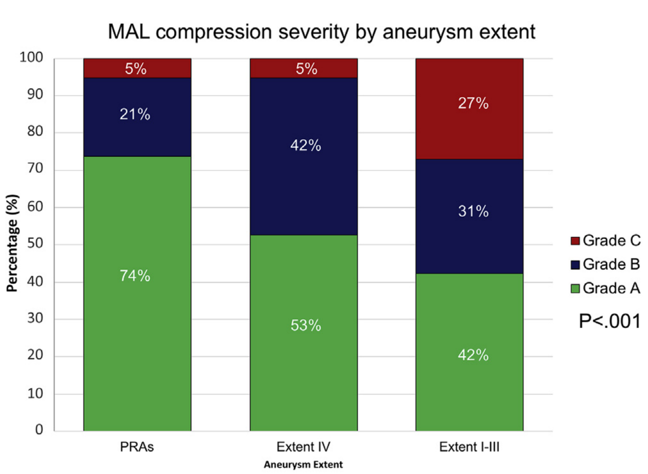


Fig 2. Bar plot representing median arcuate ligament (*MAL*) compression severity stratified by aneurysm extent. There is a significant association ($P < .001$) between MAL grade and extension of the aneurysm.

in presence of MAL compression. After stratification by aneurysm extent, a similar trend was maintained, but was still significant only for PRAAs (operating time, 247 ± 55 minutes vs 211 ± 54 minutes, $P = .034$; fluoroscopy time, 85 ± 31 minutes vs 69 ± 16 minutes, $P = .022$).

CA stenting details. Technical success for CA stenting was 99%. In a PRAA with grade C MAL compression, the CA was not successfully catheterized and the fenestration was left unstented without clinical sequelae. In another case with grade A MAL compression, the hepatic artery was successful catheterized, but owing to an unfavorable angulation it was not possible to advance the bridging stent. In this patient, the CA was stented in a retrograde fashion during a secondary procedure. Another patient with CA compression required retrograde CA catheterization through the superior mesenteric artery.

Overall, patients with MAL compression more often required the use of an adjunctive self-expandable bare metal stent (44% vs 24%; $P < .001$) or coverage of the gastric artery (44% vs 22%; $P < .001$). These results were maintained also for PRAAs (gastric artery coverage, 42% vs 0%, $P = .001$; adjunctive bare metal stent, 37% vs 3%, $P = .008$). CA stenting distal to the SA was performed in 65% of cases with MAL compression; extension over the CA main trunk with a bare metal stent was performed in five cases (four into the common hepatic artery and one into the splenic artery) with an early CA bifurcation.

Perioperative results. An intraoperative (n = 6 [2.6%]) or early (n = 1 [0.4%]) revision of the celiac branch was required in seven cases (5% vs 1%; $P = .135$). In two cases (0.9%), a flow-limiting arterial dissection was detected

Table II. Anatomic characteristics of the 230 patients with pararenal aortic aneurysm (*PRAA*) or thoracoabdominal aortic aneurysm (TAAA) treated with fenestrated-branched endovascular aortic repair (F-BEVAR) requiring stenting of the celiac artery (CA)

	Overall			PRAA			Extent IV			Extent I-III		
Variable	MAL− (n = 133)	MAL+ (n = 97)	*P* value	MAL− (n = 29)	MAL+ (n = 19)	*P* value	MAL− (n = 57)	MAL+ (n = 19)	*P* value	MAL− (n = 47)	MAL+ (n = 59)	*P* value
Prior aortic repair	67 (50.4)	57 (58.8)	.260	6 (20.7)	6 (31.6)	.609	18 (31.6)	6 (31.6)	.999	43 (91.5)	45 (76.3)	.070
Aneurysm max diameter, mm	65 ± 11	68 ± 13	<.001[a]	64 ± 13	64 ± 9	.974	62 ± 15	65 ± 9	.346	68 ± 11	70 ± 13	.371
Chronic dissection	13 (9.8)	9 (9.3)	.999	0 (0)	0 (0)	—	57 (100.0)	19 (100.0)	—	13 (27.7)	9 (15.3)	.186
Aneurysm extent			<.001[a]									.755
Type I	5 (3.8)	4 (4.1)		—	—	—	—	—	—	5 (10.6)	4 (6.8)	
Type II	30 (22.6)	38 (39.2)		—	—	—	—	—	—	30 (63.8)	38 (64.4)	
Type III	12 (9.0)	17 (17.5)		—	—	—	—	—	—	12 (25.5)	17 (28.8)	
Type IV	57 (42.9)	19 (19.6)		—	—	—	57 (100)	19 (100)	—	—	—	
Pararenal	29 (21.8)	19 (19.6)		29 (100)	19 (100)	—				—	—	
CA diameter	7.7 ± 1.3	8.1 ± 1.7	.044[a]	7.7 ± 0.9	7.9 ± 1.3	.498	7.7 ± 1.1	7.6 ± 1.5	.888	7.9 ± 1.6	8.5 ± 1.8	.138
CA emergence angle (°)	46 ± 21	27 ± 16	<.001[a]	48 ± 16	30 ± 12	<.001[a]	47 ± 20	29 ± 17	.001[a]	42 ± 24	26 ± 17	<.001[a]
CA SA (°)	158 ± 29	114 ± 29	<.001[a]	157 ± 31	108 ± 31	<.001[a]	160 ± 27	108 ± 23	<.001[a]	157 ± 31	119 ± 30	<.001[a]
SA <120°	16 (12.0)	54 (55.6)	<.001[a]	4 (13.8)	12 (63.2)	.001[a]	5 (8.8)	12 (63.2)	<.001[a]	7 (14.9)	30 (50.8)	<.001[a]
SA distance, mm	13.4 ± 5.8	14.0 ± 5.8	.511	13.5 ± 4.7	13.7 ± 5.2	.888	14.0 ± 7.4	140 ± 4.8	.982	12.3 ± 5.3	14.2 ± 6.4	.299
MAL grade												
A	—	49 (50.5)		—	14 (73.7)		—	10 (52.6)		—	25 (42.4)	
B	—	30 (30.9)		—	4 (21.1)		—	8 (42.1)		—	18 (30.5)	
C	—	18 (18.6)		—	1 (5.3)		—	1 (5.3)		—	16 (27.1)	
Stenosis >50%	19 (14.3)	48 (49.5)	<.001[a]	1 (3.4)	5 (26.3)	.029[a]	11 (19.3)	9 (47.3)	.032[a]	7 (14.9)	34 (57.6)	<.001[a]
Length of stenosis, mm	—	5.4 ± 4.4		—	2.9 ± 2.9		—	4.6 ± 3.6		—	9.4 ± 5.2	
Poststenotic ectasia >11 mm	3 (2.3)	20 (20.6)	<.001[a]	0 (0.0)	4 (21.1)	.041[a]	0 (0.0)	6 (31.6)	<.001[a]	3 (6.4)	10 (16.9)	.138
CA dissection	1 (0.8)	1 (1.0)	.999	29 (100.0)	19 (100.0)	—	0 (0.0)	1 (5.3)	0.561	1 (2.1)	0 (0.0)	.909

CA, Celiac artery; *MAL+*, presence of celiac artery compression by the median arcuate ligament; *MAL−*, absence of celiac artery compression; *SA*, shift angle.
Values are mean ± standard deviation or number (%).
[a]Statistically significant.

at the selective completion angiography and was successfully treated with true lumen access and additional stenting with a bare metal stent; one of these cases was complicated by a splenic infarction. A significant residual kink or compression of the celiac stent was detected in three cases (1.3%) on CBCT (n = 2 [0.9%]) or postoperative CTA (n = 1 [0.4%]). All of these were successfully treated with additional stenting. In one case (0.4%), the CBCT revealed a partial dislodgement of the CA stent inside the aorta; this was snared via the brachial approach, brought distally, and dilated within the iliac limb. The CA was then recatheterized and restented. One case (0.4%) of type IC endoleak was detected on CBCT and corrected with a distal extension. There were no differences in early clinical outcomes between patients with or without CA compression (Table IV).

At the univariate logistic regression, a SA of less than 120° was the most significant factor associated with CA branch revision (odds ratio [OR], 10.9; 95% confidence interval [CI], 2.3-88.9; *P* = .013). MAL compression alone (OR, 3.37; 95% CI, 0.91-15.95; *P* = .084), preoperative CA stenosis of greater than 50% (OR, 2.54; 95% CI, 0.68-9.45; *P* = .150), use of directional branches vs fenestrations (OR, 2.55; 95% CI, 0.69-12.09; *P* = .180), self-expanding vs balloon-expandable bridging stent (OR, 0.47; 95% CI, 0.02-2.60; *P* = .480), and other anatomic and procedural factors were not significantly associated (Table V).

Table III. Procedural details of the 230 patients with pararenal aortic aneurysm (*PRAA*) or thoracoabdominal aortic aneurysm (TAAA) treated with fenestrated-branched endovascular aortic repair (F-BEVAR) requiring stenting of the celiac artery (CA)

	Overall			PRAA			Extent IV			Extent I-III		
Variable	MAL− (n = 133)	MAL+ (n = 97)	*P* value	MAL− (n = 29)	MAL+ (n = 19)	*P* value	MAL− (n = 57)	MAL+ (n = 19)	*P* value	MAL− (n = 47)	MAL+ (n = 59)	*P* value
Device design			.008[a]			.396			.999			.106
Patient specific	123 (92.5)	78 (80.4)		29 (100)	18 (94.7)		54 (94.7)	18 (94.7)		40 (85.1)	42 (71.2)	
Off the shelf	10 (7.5)	19 (19.6)		0 (0)	1 (5.3)		3 (5.3)	1 (5.2)		7 (14.8)	17 (28.8)	
Preloaded guidewire/ catheter	108 (81.2)	66 (68.0)	.029[a]	26 (89.7)	18 (94.7)	.929	48 (84.2)	16 (84.2)	.999	34 (72.3)	32 (54.2)	.088
Brachial access	132 (99.2)	97 (100)	.999	29 (100)	19 (100)	—	57 (100)	19 (100)	—	46 (97.9)	59 (100)	.909
Technical success	133 (100)	95 (97.9)	.345	29 (100)	19 (100)	—	57 (100)	19 (100)	—	47 (100)	57 (96.6)	.578
Type of incorporation			<.001[a]			.999			.109			.402
Fenestration	84 (63.2)	34 (35.1)		25 (86.2)	18 (94.7)		52 (91.2)	14 (73.7)		4 (8.5)	2 (3.4)	
Directional branch	49 (36.8)	63 (64.9)		1 (3.4)	1 (5.3)		5 (8.8)	5 (26.3)		43 (91.5)	57 (96.6)	
Type of stent			.007[a]			.395			.636			.431
BE	112 (84.2)	66 (68.0)		29 (100)	18 (94.7)		54 (94.7)	17 (89.5)		29 (61.7)	31 (52.5)	
SE	21 (15.8)	31 (31.9)		0 (−)	1 (5.3)		3 (5.3)	2 (10.5)		18 (38.3)	28 (47.5)	
Additional BMS	32 (24.1)	44 (46.3)	.001[a]	1 (3.4)	7 (36.8)	.008[a]	10 (17.5)	5 (26.3)	.618	21 (44.7)	32 (56.1)	.334
No. of stents	1.3 ± 0.6	1.5 ± 0.6	<.001[a]	1.0 ± 0.2	1.4 ± 0.5	.002[a]	1.2 ± 0.4	1.3 ± 0.5	.357	1.6 ± 0.7	1.7 ± 0.6	.800
GA coverage	29 (21.8)	43 (44.3)	<.001[a]	0 (0.0)	8 (42.1)	.001[a]	9 (15.8)	4 (21.1)	.746	20 (42.6)	31 (52.5)	.154
Coverage of the SA	20 (15.0)	63 (64.9)	<.001[a]	0 (0)	9 (47.4)	.002[a]	8 (14.0)	9 (47.4)	.130	12 (25.5)	45 (76.3)	<.001[a]
Intraoperative/early revision	2 (1.5)	5 (5.2)	.135	0 (0)	2 (10.5)	.152	0 (0)	1 (5.2)	.250	2 (4.3)	2 (3.4)	.999
Contrast volume, mL	150.3 ± 56.7	162.2 ± 57.5	.121	123.7 ± 41.1	140.53 ± 41.4	.172	158.4 ± 55.4	149.0 ± 56.1	.523	157.1 ± 62.5	173.5 ± 60.1	.174
Surgery duration, minutes	160.5 ± 59.4	182.4 ± 64.1	.012[a]	139.8 ± 32.1	169.5 ± 48.6	.015[a]	163.7 ± 68.1	153.4 ± 42.5	.568	171.4 ± 59.8	195.9 ± 70.9	.087
Fluoroscopy time, minutes	80.5 ± 29.7	91.1 ± 34.3	.013[a]	68.9 ± 15.5	85.1 ± 31.3	.022[a]	80.3 ± 29.6	76.6 ± 26.9	.634	87.9 ± 34.4	97.8 ± 35.9	.158
Radiation dose, mGy	2179 ± 1705	2526 ± 1995	<.001[a]	2171 ± 1655	2335 ± 1768	.745	2265 ± 1638	3261 ± 2424	.047[a]	2079 ± 1840	2352 ± 1892	.457
EBL, mL	462.5 ± 554.9	439.6 ± 428.4	.736	450.2 ± 596.0	313.6 ± 201.6	.342	445.3 ± 614.8	319.4 ± 172.5	.396	491.0 ± 454.0	516.9 ± 513.4	.787

BE, Balloon expandable; *BMS*, bare metal stent; *GA*, gastric artery; *EBL*, estimated blood loss; *MAL+*, presence of celiac artery compression by the median arcuate ligament; *MAL−*, absence of celiac artery compression; SA, shift angle; *SE*, self-expanding.
Values are mean ± standard deviation or number (%).
[a]Statistically significant.

Midterm outcomes. Mean follow-up duration was 20 ± 13 months (range, 1-52 months). CA branch instability occurred in five cases due to type III endoleak (n = 2), type IC endoleak (n = 1), or stent kink/compression (n = 2); two of these cases had preoperative MAL compression, a SA of less than 120 was present in one, and stenting over the SA was performed in two cases (Supplementary Table, online only). At 40 months, the overall primary patency was 98 ± 1% (98 ± 2% vs 100% at 1 year, 97 ± 2% vs 100% at 2 years, and 97 ± 2% vs 100% at 3 years; *P* = .10) and secondary patency was 100%. Freedom from CA branch instability was 97 ± 2%, and this was not associated with MAL compression (hazard ratio [HR], 0.83; 95% CI, 0.14-5.02; *P* = .588) (Fig 3). Specific rates of freedom from branch instability by MAL severity were 100% for grade A, 100% for grade B, and 98 ± 4% for grade C (*P* = .600). No other anatomic or procedural factors, such as the SA (HR, 1.01; 95% CI, 0.98-1.05; *P* = .200), AE (HR, 0.99; 95% CI, 0.94-1.05; *P* = .768), preoperative stenosis of more than 50% (HR, 0.54; 95% CI, 0.06-4.88; *P* = .588), use of directional branches rather than fenestrations (HR, 1.64; 95% CI, 0.27-9.85; *P* = .585), or use of adjunctive bare metal stent (HR, 0.41; 95% CI, 0.04-3.66; *P* = .424) were significantly associated (Table V).

DISCUSSION

Radiologic signs of CA compression by the MAL may be present in up to 24% of asymptomatic patients,[7,15] usually due to a high origin of the CA or a low insertion of the diaphragmatic crura, resulting in an impingement

Table IV. Early outcomes of the 230 patients with pararenal aortic aneurysm (*PRAA*) or thoracoabdominal aortic aneurysm (TAAA) treated with fenestrated-branched endovascular aortic repair (F-BEVAR) requiring stenting of the celiac artery (CA)

	Overall			PRAA			Extent IV			Extent I-III		
Variable	MAL− (n = 133)	MAL+ (n = 97)	*P* value	MAL− (n = 29)	MAL+ (n = 19)	*P* value	MAL− (n = 57)	MAL+ (n = 19)	*P* value	MAL− (n = 47)	MAL+ (n = 59)	*P* value
Any mortality	2 (1.5)	0 (0)	.501	0 (0)	0 (0)	-	1 (1.8)	0 (0)	.999	1 (2.1)	0 (0)	.443
Any MAE	40 (30.0)	33 (34.0)	.567	14 (48.2)	7 (36.8)	.555	14 (24.5)	5 (26.3)	.999	12 (25.5)	21 (35.5)	.297
EBL >1000 mL	13 (9.7)	9 (9.2)	.999	2 (6.9)	0 (0.0)	.667	6 (10.5)	0 (0.0)	.326	5 (10.6)	9 (15.3)	.683
AKI	18 (13.5)	9 (9.2)	.408	7 (24.1)	1 (5.2)	.132	8 (14.0)	4 (21.0)	.481	3 (6.4)	4 (6.7)	.999
MI	6 (4.5)	4 (4.1)	.999	1 (3.4)	3 (15.7)	.286	4 (7.0)	1 (5.2)	.999	1 (2.1)	0 (0)	.443
Respiratory failure	3 (2.2)	3 (3.1)	.698	1 (3.4)	0 (0)	.999	1 (1.8)	1 (5.2)	.430	1 (2.1)	2 (3.4)	.999
Paraplegia	4 (3.)	7 (7.2)	.209	1 (3.4)	0 (0)	.999	0 (0)	0 (0)	-	3 (6.4)	7 (11.9)	.506
Stroke/TIA	3 (2.2)	2 (2.1)	.999	1 (3.4)	0 (0)	.999	2 (3.5)	0 (0)	.999	0 (0)	2 (3.4)	.502
Bowel ischemia	3 (2.3)	0 (0.0)	.368	1 (3.4)	0 (0.0)	.999	1 (1.8)	0 (0.0)	.999	1 (2.1)	0 (0.0)	.909

AKI, Acute kidney insufficiency; *EBL*, estimated blood loss; *MAE*, major adverse event; *MAL+*, presence of celiac artery compression by the median arcuate ligament; *MAL−*, absence of celiac artery compression; *MI*, myocardial infarction; *TIA*, transient ischemic attack.
Values are number (%).

of the proximal CA by the fibrous arch of the diaphragm. The presence of an aortic dilatation at the level of the aortic hiatus may decrease the space between the celiac axis and the MAL, causing a higher prevalence of MAL compression in patients with aortic aneurysms. This finding is confirmed by our results of a 42% prevalence of CA compression among patients affected by a PRAA or TAAA. In particular, the prevalence and severity of stenosis were correlated with aneurysm extension ($P < .001$) and diameter ($P < .001$).

Two main aspects of MAL compression may hinder the technical success and CA branch-related outcomes of F-BEVAR: the dynamic compression of the CA and the typical steep angulation between the proximal downgoing segment and shifted distal tract of the celiac axis. The first may be responsible of stent crush, fracture, or thrombosis, whereas the second may cause a stent kink and more challenging catheterization and stenting maneuvers. For these reasons, endovascular treatment of MAL syndrome has traditionally produced unsatisfactory results, and surgical or laparoscopic treatment is still advocated as the gold standard in symptomatic patients.[16-18]

However, CA stenting during F-BEVAR in asymptomatic patients represents a different scenario. In this study, the presence of MAL compression was associated with greater use of adjunctive bare metal stent ($P = .001$), a greater number of stents ($P < .001$), and a need to cover the gastric artery ($P < .001$). Also an overall longer operating time, fluoroscopy time, and higher radiation dose were observed. A similar trend was still identifiable after stratification by aneurysm extent, but statistical significance was maintained only for PRAAs. This result may be related to the fact that F-BEVAR for PRAAs usually represents a relatively easier procedure compared with TAAAs, where other factors rather than CA compression (such as longer coverage of the thoracic aorta, associated tortuosity and elongation of the aorta, and concomitant chronic dissection) may have a greater impact on the overall complexity of the procedure.

Follow-up outcomes of CA stenting in F-BEVAR are generally favorable. Mastracci et al[3] described a 3.6% rate of adverse events in 109 celiac stents, in a cohort of PRAAs and TAAs. Data from the same group[19] showed a slightly higher 4.5% incidence in 110 incorporated CAs, specifically for types II and III TAAA. Panuccio et al[20] demonstrated CA bridging stent instability in 5.8% of 104 cases of F-BEVAR, whereas the rate of adverse events during the follow-up was 3% in 208 CAs in a European multicenter study.[21]

In our experience, overall freedom from CA branch instability was 97 ± 2%, and MAL compression was not associated with inferior early or long-term outcomes. These results are in line with Wattez et al,[22] who described the results of CA stenting in 113 F-BEVAR for PRAA or TAAA, with good results in either the presence or absence of MAL compression. They also reported a more frequent use of bail-out endovascular maneuvers to achieve CA stenting in case of MAL compression, which was higher than observed in our series (14% vs 4%). In our experience, the more frequent use of directional branches, preloaded guidewires, and arm access, may have facilitated catheterization and stenting of the CA in settings with MAL compression.

The impact of target artery angle patterns and their impact on F-BEVAR outcomes have been studied for renal arteries,[23-25] showing unfavorable outcomes in case of upward-oriented renal arteries treated with downgoing directional branches. However this anatomic aspect has not been considered adequately for the CA. The results of this study suggest that the takeoff angle of the celiac axis does not influence early or long-term outcomes, although a SA of less than 120° was the only

Table V. Univariate logistic regression for intraoperative or early (30 days) revision of the celiac artery (*CA*) branch and Cox proportional hazards for CA branch instability

Variable	OR/HR (95% CI)	*P* value
Early CA revision		
MAL compression	3.37 (0.91-15.95)	.084
Stenosis >50%	2.54 (0.68-9.45)	.150
SA	0.98 (0.95-1.01)	.189
SA <120°	10.1 (2.47-68.8)	.037[a]
Emergence angle	0.98 (0.95-1.02)	.532
SE stent	0.47 (0.02-2.60)	.480
Directional branch	2.55 (0.69-12.09)	.180
GA coverage	3.50 (0.96-14.07)	.058
Aneurysm diameter	0.96 (0.90-1.03)	.325
Aneurysm extent		
PRAA	Ref.	
Type IV	0.31 (0.01-3.28)	.340
Type I-III	0.90 (0.17-6.67)	.907
CA instability		
MAL compression	0.83 (0.14-5.02)	.588
Stenosis >50%	0.55 (0.06-4.89)	.848
SA	1.02 (0.98-1.05)	.247
SA <120°	0.47 (0.05-4.21)	.501
Emergence angle	0.99 (0.94-1.05)	.768
Directional branch	1.64 (0.27-9.85)	.585
SE stent	0.03 (NA)	.200
GA coverage	0.49 (0.05-4.38)	.523
Aneurysm diameter	1.03 (0.97-1.08)	.276

CI, Confidence interval; *GA*, gastric artery; *HR*, hazard ratio; *MAL*, median arcuate ligament; *OR*, odds ratio; *PRAA*, pararenal aortic aneurysm; *SA*, shift angle; *SE*, self-expanding.
[a]Statistically significant.

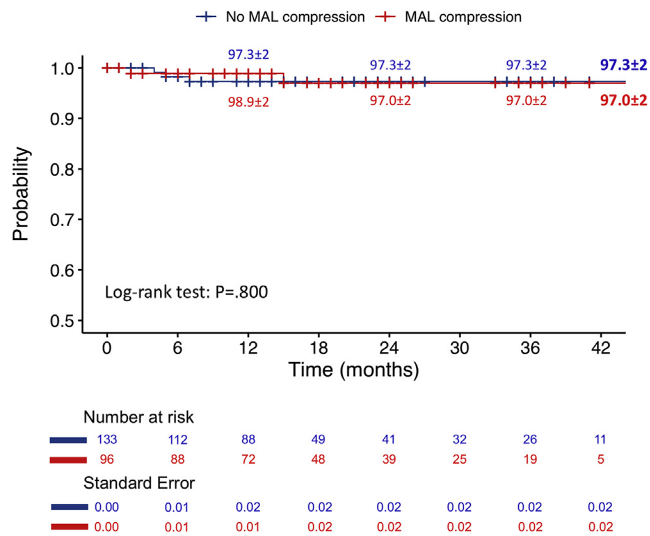


Fig 3. Kaplan-Meier estimates of freedom from celiac artery (CA) branch instability, stratified by presence of median arcuate ligament (*MAL*) compression. Standard error <10%.

predictor of intraoperative or early revision of the CA branch (OR, 10.1; $P = .037$).

Our results are the evolution of a robust F-BEVAR program and the evolving advances in technology and devices. Our finding that fenestrations rather than directional branches ($P = .180$) or the use of a self-expanding rather than a balloon-expandable bridging stent ($P = .480$) were not significantly associated with early or late outcomes of CA stenting is likely the result of appropriate decisions made based on anatomic characteristics (such as aneurysm morphology, diameter, and extent, as well as orientation of the target vessel), apart from the presence of MAL compression. In particular, a few technical tips may have been helpful in achieving good results for the CA. In all cases, arm access with preloaded guidewires is usually preferred for CA cannulation and stenting, if not contraindicated. Ten to 15 mm of sealing length into the CA is usually desired, and 65% of cases with MAL compression required to land over the SA. In some cases, the deployment of the stent in proximity of the SA may trigger a kink at the transition between the distal edge and the native CA; in this case, a self-expandable bare metal stent is useful to accommodate the transition to the native anatomy. In case of a short distance before the SA, an adjunctive balloon-expandable stent may be used to reinforce the bridging stent at the flexion point. A routine technical assessment with contrast-enhanced CBCT is of particular importance, especially for steep angulations, because it provides a high sensitivity in the identification of intraoperative compressions or kinks that may not be detectable at the DSA.[11,12] This strategy also allows the immediate correction of eventual morphologic defects, possibly limiting the number of late complications. Interestingly, no specific type of stent showed better results in our experience, but the high technical success (98%) and freedom from midterm complications (97%) seem to support a strategy of incorporation of the CA, rather than a primary coverage, regardless the presence of difficult anatomies.

Our study is strengthened by the prospective collection of clinical and procedural data, the careful evaluation of anatomic CA details, and the use of standardized protocols to design the aortic stent graft and to choose the bridging stents. However, this study has notable limitations. This retrospective, single-center review may not have generalizable results. In addition, the number of events is low and this factor limits the power of the statistical analysis. This limitation is potentiated by stratification by aneurysm extent. Thus, we were not able to perform any multivariable analyses in the present study. In regard to detection bias, the definition of CA compression was based on static CTA images without an assessment for dynamic MAL compression. Last, the interpretation of the completion angiography, CBCT, and postoperative findings were at the discretion of the primary operator, as was the decision to perform a reintervention. However, all cases were performed by one operator (G.S.O.), limiting interprovider variability.

CONCLUSIONS

MAL compression is more common in extent I to III TAAAs, and imposes additional challenges for CA stenting in F-BEVAR. This may require additional bare metal stenting, gastric artery coverage, or early revision, especially in presence of an angulation of less than 120°. However, excellent mid-term results can be achieved for CA incorporation despite MAL compression and are not a barrier to effective aneurysm complex endovascular aortic aneurysm treatment.

AUTHOR CONTRIBUTIONS

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

REFERENCES

1. Oderich GS, Ribeiro M, Hofer J, Wigham J, Cha S, Chini J, et al. Prospective, nonrandomized study to evaluate endovascular repair of pararenal and thoracoabdominal aortic aneurysms using fenestrated-branched endografts based on supraceliac sealing zones. J Vasc Surg 2017;65:1249-59.e10.
2. Oderich GS, Ribeiro MS, Sandri GA, Tenorio ER, Hofer JM, Mendes BC, et al. Evolution from physician-modified to company-manufactured fenestrated-branched endografts to treat pararenal and thoracoabdominal aortic aneurysms. J Vasc Surg 2019;70:31-42.e7.
3. Mastracci TM, Greenberg RK, Eagleton MJ, Hernandez AV. Durability of branches in branched and fenestrated endografts. J Vasc Surg 2013;57:926-33; discussion: 933.
4. Verhoeven EL, Katsargyris A, Oikonomou K, Kouvelos G, Renner H, Ritter W. Fenestrated endovascular aortic aneurysm repair as a first line treatment option to treat short necked, juxtarenal, and suprarenal aneurysms. Eur J Vasc Endovasc Surg 2016;51:775-81.
5. Mastracci TM, Eagleton MJ, Kuramochi Y, Bathurst S, Wolski K. Twelve-year results of fenestrated endografts for juxtarenal and group IV thoracoabdominal aneurysms. J Vasc Surg 2015;61:355-64.
6. Simons JP, Podder S, Dossabhoy SS, Wyman AS, Arous EJ, Judelson DR, et al. Fenestrated/branched endovascular aortic aneurysm repair using a supraceliac aortic proximal seal zone versus an infraceliac aortic proximal seal zone. Ann Vasc Surg 2020;62:213-22.
7. Kim EN, Lamb K, Relles D, Moudgill N, DiMuzio PJ, Eisenberg JA. Median arcuate ligament syndrome-review of this rare disease. JAMA Surg 2016;151:471-7.
8. Chaikof EL, Fillinger MF, Matsumura JS, Rutherford RB, White GH, Blankensteijn JD, et al. Identifying and grading factors that modify the outcome of endovascular aortic aneurysm repair. J Vasc Surg 2002;35:1061-6.
9. Petnys A, Puech-Leão P, Zerati AE, Ritti-Dias RM, Nahas WC, Neto ED, et al. Prevalence of signs of celiac axis compression by the median arcuate ligament on computed tomography angiography in asymptomatic patients. J Vasc Surg 2018;68:1782-7.
10. Sugae T, Fujii T, Kodera Y, Kanzaki A, Yamamura K, Yamada S, et al. Classification of the celiac axis stenosis owing to median arcuate ligament compression, based on severity of the stenosis with subsequent proposals for management during pancreatoduodenectomy. Surgery 2012;151:543-9.
11. Tenorio ER, Oderich GS, Sandri GA, Ozbek P, Kärkkäinen JM, Macedo TA, et al. Impact of onlay fusion and cone beam computed tomography on radiation exposure and technical assessment of fenestrated-branched endovascular aortic repair. J Vasc Surg 2019;69:1045-58.e3.
12. Tenorio ER, Oderich GS, Sandri GA, Ozbek P, Kärkkäinen JM, Vrtiska T, et al. Prospective nonrandomized study to evaluate cone beam computed tomography for technical assessment of standard and complex endovascular aortic repair. J Vasc Surg 2020;71:1982-93.e5.
13. Chaikof EL, Dalman RL, Eskandari MK, Jackson BM, Lee WA, Mansour MA, et al. The Society for Vascular Surgery practice guidelines on the care of patients with an abdominal aortic aneurysm. J Vasc Surg 2018;67:2-77.e2.
14. Fillinger MF, Greenberg RK, McKinsey JF, Chaikof EL. Society for Vascular Surgery Ad Hoc Committee on TEVAR Reporting Standards. Reporting standards for thoracic endovascular aortic repair (TEVAR). J Vasc Surg 2010;52:1022-33.e15.
15. Horton KM, Talamini MA, Fishman EK. Median arcuate ligament syndrome: evaluation with CT angiography. Radiographics 2005;25:1177-82.
16. Delis KT, Gloviczki P, Altuwaijri M, McKusick MA. Median arcuate ligament syndrome: open celiac artery reconstruction and ligament division after endovascular failure. J Vasc Surg 2007;46:799-802.
17. Matsumoto AH, Angle JF, Spinosa DJ, Hagspiel KD, Cage DL, Leung DA, et al. Percutaneous transluminal angioplasty and stenting in the treatment of chronic mesenteric ischemia: results and longterm followup. J Am Coll Surg 2002;194:S22-31.
18. Columbo JA, Trus T, Nolan B, Goodney P, Rzucidlo E, Powell R, et al. Contemporary management of median arcuate ligament syndrome provides early symptom improvement. J Vasc Surg 2015;62:151-6.
19. Sylvan J, Brier C, Wolski K, Yanof J, Goel V, Kuramochi Y, et al. Impact of alterations in target vessel curvature on branch durability after endovascular repair of thoracoabdominal aortic aneurysms. J Vasc Surg 2016;63:634-41.
20. Panuccio G, Bisdas T, Berekoven B, Torsello G, Austermann M. Performance of bridging stent grafts in fenestrated and branched aortic endografting. Eur J Vasc Endovasc Surg 2015;50:60-70.
21. Mastracci TM, Carrell T, Constantinou J, Dias N, Martin-Gonzalez T, Katsargyris A, et al. Editor's Choice - Effect of branch stent choice on branch-related outcomes in

complex aortic repair. Eur J Vasc Endovasc Surg 2016;51:536-42.

22. Wattez H, Martin-Gonzalez T, Lopez B, Spear R, Clough RE, Hertault A, et al. Results of celiac trunk stenting during fenestrated or branched aortic endografting. J Vasc Surg 2016;64:1595-601.
23. Conway BD, Greenberg RK, Mastracci TM, Hernandez AV, Coscas R. Renal artery implantation angles in thoracoabdominal aneurysms and their implications in the era of branched endografts. J Endovasc Ther 2010;17:380-7.
24. Gallitto E, Faggioli G, Pini R, Mascoli C, Ancetti S, Abualhin M, et al. Renal artery orientation influences the renal outcome in endovascular thoraco-abdominal aortic aneurysm repair. Eur J Vasc Endovasc Surg 2018;56:382-90.
25. Tenorio ER, Kärkkäinen JM, Mendes BC, DeMartino RR, Macedo TA, Diderrich A, et al. Outcomes of directional branches using self-expandable or balloon-expandable stent grafts during endovascular repair of thoracoabdominal aortic aneurysms. J Vasc Surg 2020;71:1489-502.e6.

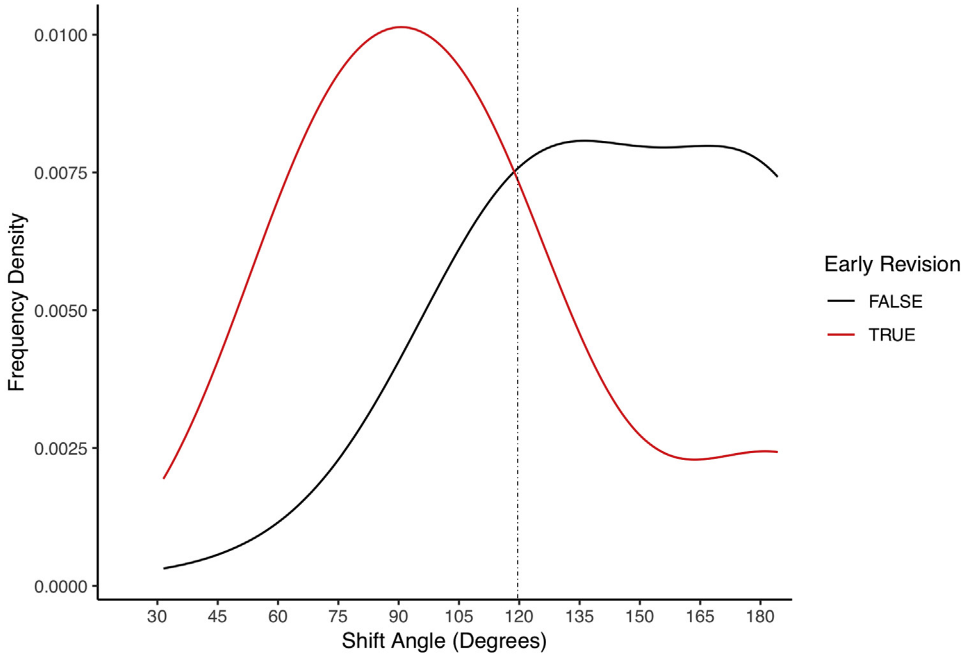
Submitted Apr 15, 2020; accepted Jul 19, 2020.

Additional material for this article may be found online at www.jvascsurg.org.

Supplementary Table (online only). Modalities of failure of the incorporated celiac artery (*CA*) during follow-up

ID	Aneurysm Extent	Type of incorporation	Identifiable risk factors	Complication	Treatment
1	IV	Fenestration	Atherosclerotic stenosis	Type IIIc endoleak	Relining with balloon-expandable covered stent
2	II	Fenestration	SA <120°	Type IIIc endoleak	Relining with balloon-expandable covered stent
3	II	Directional branch	MAL compression (grade C)	Severe stenosis of the CA with concomitant stenosis of the SMA	Relining with balloon-expandable covered stent
4	III	Directional branch	MAL compression (grade C)	Severe kink of the CA with concomitant stenosis of the SMA	Relining with balloon-expandable covered stent
5	II	Directional branch	None	Type Ic endoleak	Relining with balloon-expandable covered stent

MAL, Median arcuate ligament; *SA*, shift angle; *SMA*, superior mesenteric artery.



Supplementary Fig (online only). Frequency density distribution of the value of the shift angle (SA), stratified by necessity to perform an early revision of the CA. The optimal cutoff to discriminate between patients needing revision and uncomplicated cases was 120°.