Results of current endovascular treatments for visceral artery aneurysms

Aaron T. Fargion, MD, Roberto Falso, MD, Sara Speziali, MD, Brigida Biancofiore, MD, Davide Esposito, MD, Elena Giacomelli, MD, PhD, Walter Dorigo, MD, *and* Raffaele Pulli, MD, *Florence, Italy*

ABSTRACT

Objective: This single-center retrospective cohort study aimed to analyze the early and long-term results of endovascular treatment for true visceral artery aneurysms (VAAs). Moreover, a comparison with the results of our previously published historical series of open surgical procedures was performed.

Methods: From January 2008 to December 2021, 78 consecutive patients were treated at our institution for true VAAs. All demographic data, procedural details, perioperative outcomes, and follow-up data were collected prospectively from a dedicated database. A retrospective analysis identified 72 patients who underwent endovascular surgery. Early results were analyzed in terms of technical success, conversion to open surgery, mortality, and local and systemic morbidities. Follow-up results were analyzed in terms of survival, need for open or endovascular reintervention, and freedom from complications at the level of the treated visceral artery. These results were then compared with those of our historical open surgical group (1982-2007), which included 54 interventions.

Results: In four cases, the planned endovascular procedure could not be completed, and the overall technical success rate was 94.5%. No deaths occurred during the hospital stay or within 30 days after surgery. Overall, the 30-day perioperative complication rate was 5.8%, with an early reintervention rate of 2.9%. The median follow-up time was 29 months (range, 1–132 months). The estimated 7-year survival rate was 88% (standard error [SE]. 0.05). The estimated 7-year aneurysm-related complication-free rate was 85.5% (SE, 0.06), with reintervention-free and aneurysm-related complication-free survival rates of 93.3% (SE, 0.04) and 75.6% (SE, 0.07), respectively. At the 7-year follow-up, the survival rate was similar between the endovascular and open groups. There was a trend toward a higher aneurysm-related complication rate in the endovascular group than in the open group (14.5% vs 6.4%; $P = .07$). However, no significant differences in reintervention-free and overall estimated aneurysm-related complication-free survival rates were found between the two groups.

Conclusions: Endovascular repair is safe and effective in patients with VAAs, with low perioperative complication rates. The long-term outcomes were satisfactory and comparable with those of the historical series of open surgical repairs. Even if there is a trend toward a higher risk of late aneurysm-related complications among endovascular patients, it does not imply an increased need for late reinterventions. (J Vasc Surg 2023;78:387-93.)

Keywords: Visceral artery aneurysm; Endovascular repair; Open surgery; Endovascular techniques; Late results

True visceral artery aneurysms (VAAs) are rare, accounting for <5% of all intra-abdominal aneurysms, and are primarily caused by atherosclerosis or other degenerative diseases.[1] Rupture of the VAA is the main complication; it is frequently the clinical picture of onset and is burdened with extremely high mortality rates.[2] The risk of rupture tends to increase with the increase in the lesion size. Thus, elective surgical treatment for aneurysms >2 cm is advocated by most authors and guidelines.[3-6] More recently, the Society for Vascular Surgery guidelines[1] have identified different surgical indications based on which artery is involved, ranging from 3 cm lesions for renal, splenic, and hepatic arteries to treatment of all aneurysms, regardless of size for smaller arteries or distal branches.

Open surgical repair has been considered for years the treatment of choice, providing low perioperative mortality and morbidity rates[7] and excellent durability in the long term.[8] In recent years, endovascular surgery has emerged as a safe, reliable, and minimally invasive treating method for VAAs.[9] As a consequence, the latest guidelines recommend an endovascular-first approach, when anatomically feasible.[1] The majority of the published studies regarding open and endovascular

From the Section of Vascular Surgery, Department of Excellence of Experimental and Clinical Medicine, University of Florence.

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Correspondence: Walter Dorigo, MD, Section of Vascular Surgery, Department of Excellence of Experimental and Clinical Medicine, University of Florence Largo Brambilla 3, 50134 Florence, Italy (e-mail: walter.dorigo@unifi.it).

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treatment of VAAs are noncomparative[10]; only a few directly compare the outcomes of these two techniques.[11-13] The aim of the present study was to retrospectively analyze the early and long-term results of endovascular treatment of VAA in our single-center experience. Moreover, a comparison with the results of our historical series of open surgical procedures was included in the study.[8] The manuscript was prepared using the STROBE guidelines.[14]

ARTICLE HIGHLIGHTS

- **Type of Research:** Single-center retrospective cohort study
- **Key Findings:** Endovascular treatment of visceral artery aneurysms in 72 patients resulted in a 94.5% technical success, no perioperative mortality, and a 2.9% early reintervention rate. The comparison of late results with those of our historical series of open interventions showed no differences in 7-year survival and reinterventions.
- **Take Home Message:** Endovascular repair of visceral artery aneurysms is safe and effective, with low perioperative complication rates and long-term outcomes that are well comparable with those of open surgical repair.

METHODS

Study group, indications for treatment, and preoperative assessment. From January 2008 to December 2021, 78 consecutive patients were treated at our institution for a true VAA. Demographic data, technical details, perioperative outcomes, and follow-up data were collected prospectively in a dedicated database. Preoperatively, all patients gave their consent to the use of their clinical data for research purposes and for this reason the institutional review board approval was not required because only deidentified data were used.

A retrospective analysis revealed that 72 patients underwent endovascular repair, whereas 6 patients underwent open surgical repair. Our indications for treatment were the presence of a symptomatic aneurysm, irrespective of its diameter, and an asymptomatic aneurysm with a maximum diameter of >2 cm. In selected cases (young women, aneurysms involving a collateral artery, and small saccular lesions), the indication for surgery was discussed and decided case by case; in addition, lesions <2 cm were considered for treatment. In the last year of our study, after the publication of the Society for Vascular Surgery guidelines,[1] we decided to treat asymptomatic hepatic, splenic, and renal aneurysms when the maximum diameter was >3 cm.

The aortoiliac vessels, visceral and renal arteries, and lower limbs were preoperatively assessed using duplex ultrasound (DUS) examination. The entire thoracoabdominal aorta and visceral vessels were assessed using computed tomography angiography (CTA).

All cases were first evaluated endovascularly using a dedicated imaging software (Aquarius iNtuition, TeraRecon, Durham, NC). The absence of suitable anatomy (inadequate necks, proximal and distal sealing zones, severe tortuosity, or high risk of visceral ischemia), the presence of contraindications for iodine contrast medium use, or any documented allergy to stent or coil components were considered as exclusion criteria for endovascular treatment. Open surgery was performed in such patients. During the study period, six patients underwent open surgery; only one open surgery was performed after 2014. Two patients had stage 4 chronic renal failure on the basis of the National Kidney Foundation Kidney Disease Outcomes Quality Initiative guidelines and two had a giant splenic artery aneurysm not amenable for endovascular treatment. One patient had concomitant aneurysms of the infrarenal abdominal aorta and common hepatic artery, which required combined open surgical repair. The remaining patient had a hepatic artery aneurysm with a concomitant chronic occlusion of the celiac trunk, requiring an iliohepatic bypass. These six patients were excluded from the analysis.

The results of the 72 endovascular procedures were then compared with those of our historical open surgical group (1982-2007) of 55 interventions, whose indications, characteristics, and surgical details have been described previously.[8]

Endovascular technique. All interventions were performed in the early years by vascular surgeons in an angiography suite. As of 2017, the interventions were performed in a hybrid suite. Local anesthesia was administered in all cases; intravenous sedation or analgesia were used as needed. A unilateral femoral approach was preferred; in selected cases, simultaneous or exclusive left brachial access was obtained. All patients were given intravenous sodium heparin at the time of arterial access. The endovascular strategy was based on the aneurysmal morphology and characteristics of the inflow and outflow vessels.[9]

In patients with saccular aneurysms or when the preservation of collaterals arising from the aneurysm was not needed, coil packing or sandwich embolization was performed. Detachable microcoils were delivered with a microcatheter (2.2F-2.7F) after selective cannulation of the target vessel with a 4F hydrophilic diagnostic catheter. In patients with fusiform aneurysms with an adequate proximal and distal sealing zone, a covered stent was preferred; in addition, we routinely performed ballooning of the proximal and distal landing zones. A flow diverter stent was used in selected lesions requiring vessel bifurcation or collateral preservation. A single

Table I. Comorbidities and risk factors for atherosclerosis in the study group

	Patients (n = 72)
Female sex	39 (54%)
Median age	65.5 years
Active smoker	10 (14%)
Past smoker	14 (19%)
Coronary artery disease	16 (22%)
Chronic obstructive pulmonary disease	17 (24%)
Hyperlipemia	15 (21%)
Arterial hypertension	35 (49%)
Diabetes mellitus	4 (5.5%)

antiplatelet agent was administered postoperatively. However, if a stent was deployed, patients were prescribed double antiplatelet therapy for ≥1 year.

Follow-up, outcomes, and statistics. DUS examination and CTA were performed in the first postoperative month. Thereafter, DUS examination was performed every 6 months. When DUS examinations suggested the presence of complications or were not conclusive, a CTA was performed. All DUS examinations were performed by board-certified physicians following the standard practice guidelines; the diameter of the treated aneurysm and the presence of leaks were evaluated. In our historical published group, follow-up consisted of clinical and ultrasound examinations at 1 and 12 months, and annually thereafter. All patients underwent ≥1 CT scan during follow-up.

Perioperative results were assessed in terms of technical success, conversion to open surgery, mortality, and local and systemic morbidities. Technical success was defined as stopping the aneurysmal flow in patients undergoing coiling,[13] successful exclusion in patients undergoing covered stent placement, and adequate placement of the device in the planned position in patients treated with flow diverter stents. Conversion to open surgery was defined as the need for immediate surgical repair after a technical failure. Local and systemic morbidity was defined as any condition that required local surgical treatment or caused prolonged hospitalization.

Follow-up outcomes were analyzed in terms of survival, need for open or endovascular reintervention, and freedom from aneurysm-related complications. Aneurysm-related complications were defined as all complications occurring at the target vessel level.

Statistical analysis was performed using SPSS for Windows (version 28.0; SPSS Inc., Chicago, IL). Early results were analyzed using the χ^2 test and Fisher's exact test as appropriate. Follow-up data were analyzed using life-table analysis and Kaplan-Meier curves. The outcomes of the endovascular procedures were compared with those of the historical open surgery group. The perioperative results were compared using the χ^2 test and long-term results with the log-rank test.

RESULTS

Clinical and anatomical characteristics. Patients were predominantly females (39 of 72 cases [54%]) with a median age of 65.5 years (range, 23-85 years). Comorbidities and risk factors for atherosclerosis are listed in Table I. The sites of treated VAAs are listed in Table II. The mean preoperative diameter of the treated lesions was 24.8 ± 10.5 mm; the mean aneurysmal diameter of each target visceral segment is presented in Table II.

All but three patients had asymptomatic aneurysms, which were found incidentally during diagnostic assessments for other reasons. Two patients had chronic abdominal pain; one patient had chronic tamponade rupture of a pancreaticoduodenal artery aneurysm. The other patient presented with hemorrhagic shock owing to rupture of a common hepatic artery aneurysm. Eleven patients had a concomitant aneurysm involving other arteries, of which 10 were abdominal aortic aneurysms not requiring repair. The eleventh patient had other VAAs not requiring surgical intervention; a renal artery aneurysm that was amenable for treatment was detected during follow-up. One patient's asymptomatic popliteal artery aneurysm was treated several years after its detection. Clinical, laboratory, and radiologic findings did not suggest the presence of mycotic aneurysms in the study group.

Procedural details. All surgeries were performed under locoregional anesthesia, with percutaneous access in majority of the cases (69/72 [96%]; 67 common femoral and 2 brachial arteries). A limited DUS-guided surgical cut-down was performed in three patients; two at the proximal left brachial artery and one at the common femoral artery.

Coil embolization was planned in 56 cases, sandwich embolization in 1, covered stent placement in 12, and flow diverter stent placement in 3. However, in four patients, the planned procedure could not be completed. A renal artery aneurysm could not be cannulated selectively in one patient. In one patient with a fusiform splenic artery aneurysm without a suitable landing zone for a covered or diverter stent, the treatment was delayed owing to the high risk of coil migration (stent-assisted coil embolization). In two patients with splenic aneurysms, blood flow in the lesion could not be excluded. All four patients refused traditional surgery and underwent a clinical follow-up program. The overall technical success rate was 94.5% (68/72). The intervention type for each lesion in patients in whom technical success was achieved is shown in Table III.

Table II. Site of the treated visceral artery aneurysms (VAAs) and mean preoperative diameters

	Patients (n = 72)	Mean preoperative diameter, mm	Size range, mm
Splenic artery	46 (64%)	26.3±10.3	13-70
Hepatic artery	7 (10%)	25±13.7	18-55
Renal artery	7 (10%)	16.5±5.1	10-25
Pancreaticoduodenal artery	5 (7%)	25.6±11	7-35
Gastroduodenal artery	3 (4%)	15±7	10-23
Celiac trunk	3 (4%)	23.3±2.5	21-26
Superior mesenteric artery	1 (1%)	20	-

An average of 4 coils per aneurysm was delivered during embolization, with a minimum of 1 and a maximum of 16. An average of 1.5 stents per lesion was implanted, with an average artery coverage and stent diameter of 53.0 mm and 5.5 mm, respectively. Adjunctive endovascular procedures were performed in four cases. Additional covered stents were implanted endovascularly in two patients; one for a type I B endoleak and one for inefficient sac embolization. Embolization of the proximal and distal branches of the aneurysm were required on one patient after incomplete sac embolization. In one patient, a plug was deployed in the common hepatic artery before placing a covered stent from the celiac trunk to the splenic artery.

Intraprocedural complications developed in three patients. In two patients, a distal migration in the efferent coil branch was retrieved using the goose neck technique. In the third patient undergoing covered stenting of the splenic artery, a limited dissection was observed just distal to the stent without alteration of the downstream flow; therefore, it was left untreated.

The mean duration of the procedure was 66±28 minutes (range, 20–150 minutes).

Perioperative results. No deaths occurred during the hospital stay or within 30 days after surgery. However, two major perioperative complications were noted. One patient who underwent embolization of a splenic artery aneurysm presented on the first postoperative day with intense pain in the left flank associated with hypotension and tachycardia. An emergency CTA showed migration of the three implanted coils into the splenic parenchyma, with concomitant splenic infarction. The patient underwent embolization of the aneurysmal sac using coils and polymer glue on the same day; the symptoms then disappeared within 72 hours without the need for splenectomy. A second patient, who underwent covered stenting for a splenic artery aneurysm, presented with severe left flank pain radiating to the left shoulder. A CT scan revealed a significant increase in the aneurysm size (from 3.3 to 4.5 mm), which was associated with an endoleak at the distal edge of the stent. Coil embolization of the aneurismal sac was successfully performed. Both patients were discharged without clinical sequelae. Minor complications occurred in two patients (one had postoperative anemia requiring a blood transfusion and the other had acute urinary retention).

Overall, the mean postoperative hospital stay was 2.7 days (range, 1-10 days). The therapy prescribed at discharge consisted of single or double antiplatelet therapy in 38 patients and low-molecular-weight heparin in 29. Oral anticoagulants that were already being consumed for cardiac diseases in five patients were continued at home. There were no hospital readmissions, new complications, or reinterventions in the first month of follow-up. Overall, the 30-day perioperative complication rate was 5.8% (4 complications among the 68 patients who had technical success), with an early reintervention rate of 2.9%.

Follow-up results. The median duration of follow-up was 29 months (range, 1-132 months). The follow-up covered 97.3% of the study group (70/72 patients). Eight deaths occurred during follow-up, three from cancer, two from cardiac disease, and one from acute respiratory failure owing to coronavirus disease 2019-related interstitial pneumonia. In two cases, the cause of death was unknown. The estimated 7-year survival was 88% (standard error [SE], 0.05).

The average diameter of the treated aneurysm at the most recent follow-up was significantly decreased in comparison with the preoperative values (24.8 mm vs 18.8 mm; 95% confidence interval, 4.6-7.7; $P < .001$).

Four aneurysm-related complications were reported. One patient, who underwent coil embolization of a splenic artery aneurysm, presented with a residual sac perfusion at the 12-month follow-up. Sac perfusion had subsequently regressed by the 24-month follow-up. In one case, complete asymptomatic thrombosis of a multilayer stent was identified at the level of the common hepatic artery; the patient was left untreated. Two patients treated for splenic aneurysms developed a new aneurysm distal to the original segment during follow-up. One patient, who was treated with a covered stent, developed a new small centimetric aneurysm. The patient is currently stable and undergoing periodic follow-up. The second patient who was treated with coil embolization showed aneurysmal evolution (25 mm in diameter) of the distal arterial tract at the 42-month follow-up. The patient underwent a second successful coil embolization with no further evolution at subsequent controls.

No ruptures or aneurysm-related deaths were recorded in the study. None of the patients in whom technical

Table III. Type of intervention for each kind of lesion in patients with technical success

	Coil embolization (n = 53)	Covered stent (n = 12)	Flow-diverter stent (n = 3)
Splenic artery	36	7	-
Hepatic artery	3	2	2
Renal artery	5	1	-
Pancreaticoduodenal artery	5	-	-
Gastroduodenal artery	3	-	-
Celiac trunk	1	1	1
Superior mesenteric artery	-	1	-

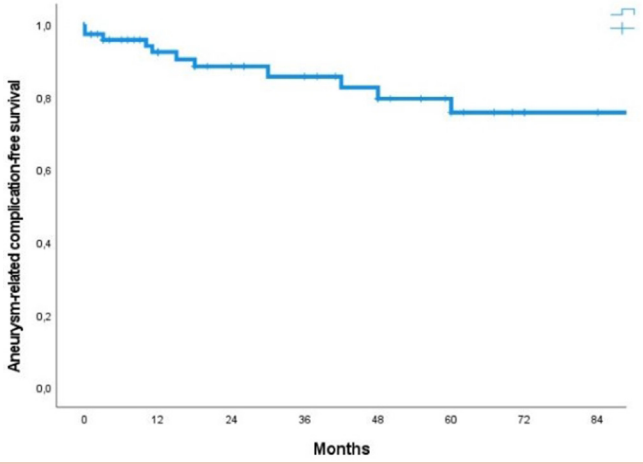

Fig. Kaplan-Meyer curve for aneurysm-related complication-free survival at 7 years with number of patients at risk. *S.E.*, standard error,

failure occurred showed progression of the aneurysm during follow-up; therefore, no treatment of the lesions has been necessary to date. The estimated 7-year aneurysm-related complication-free and reintervention-free rates were 85.5% (SE, 0.06) and 93.3% (SE, 0.04), respectively. The estimated 7-year complication-free survival rate was 75.6% (SE, 0.07) (Fig).

Comparison with the historical series of open interventions. In our open series, a patient died perioperatively from necrotic hemorrhagic pancreatitis (1/55 [1.8%]). Furthermore, there were two major complications (2/55 [3.6%]), one nonfatal pancreatitis, and one retroperitoneal hematoma requiring surgical revision. All these patients underwent resection and reconstruction with end-to-end anastomosis for a splenic aneurysm.

No significant differences in mortality (0% vs 1.8%; $P = .3$), major complications (2.9% vs 3.6%; $P = .7$) or reinterventions (2.9% vs 1.8%; $P = .3$) were found between the two groups in the perioperative period. The average length of hospitalization (9.7±5.5 vs 2.7 days; $P < .001$) and median follow-up duration (82 vs 29 months; $P < .001$) were higher in the open group than in the endovascular group. The estimated 7-year survival rate was similar between the two groups (88% vs 87.5% in the endovascular vs open surgical groups; SE, 0.05; $P = .8$; log rank 0.2).

At the 7-year follow-up, there was a trend toward a higher aneurysm-related complication rate among the endovascular group than among the open group (14.5% vs 6.4%; SE, 0.04; $P = .07$; log rank, 1.6). However, no significant differences in 7-year reintervention-free (93.3% vs 94% in the endovascular vs open group; SE, 0.05; $P = .9$; log rank, 0.07) and overall aneurysm-related complication-free survival rates (79% vs 75.6%; SE, 0.06; $P = .9$; log rank, 0.03) were found between the two groups. The perioperative and follow-up results of the two groups are summarized in Table IV.

DISCUSSION

Overall results. Several recently published case series have reported that endovascular repair of VAAs, when feasible, is safe and effective, with low rates of perioperative complications and mortality. Furthermore, its long-term results are similar to those obtained with open surgical repair, particularly for elective procedures.[9-11,15] In the emergency setting, endovascular treatment is reportedly safe in hemodynamically stable patients with a ruptured aneurysm; however, open surgery remains the gold standard in hemodynamically unstable patients.[13] The results of this study are consistent with those of previous study.[12] The technical success rate of the endovascular cohort was 94.5%, with only a few major perioperative complications, no perioperative deaths, and a low incidence of early reinterventions.

Comparison with open surgery. A comparison of the open and endovascular approaches is difficult; a majority of the recently published series are retrospective non-comparative studies. Furthermore, studies comparing the two treatment modalities are limited and show a significant selection bias.[10,16] Moreover, the growing diffusion of endovascular techniques and improvements in materials and devices has made endovascular approach the treatment of choice for VAAs. Even in our experience, open surgical intervention was performed only once in the last 9 years, which makes a prospective comparison difficult and of little use. A recent meta-analysis by Barrionuevo et al[10] suggests a possible equipoise in mortality between open surgery and endovascular repair of VAAs. Open surgery showed a higher rate of perioperative complications and a longer hospital stay, whereas endovascular interventions presented a higher early reintervention rate.[10] We obtained similar findings in our

Table IV. Perioperative and follow-up results in the two groups

	Study group (endo)	Historical group (open)	*P* value
Mean postoperative hospital length of stay, days	2.7±1.7	9.7±5.5	<.001
Perioperative mortality	0	1 (1.8%)	.3
Perioperative nonfatal complications	2.9%	3.6%	.7
Perioperative reinterventions	2.9%	1.8%	.3
Median follow-up, months	29	82	<.001
7-Year survival	88%	87.5%	.8
7-Yeat freedom from reintervention	93.3%	94%	.9
7-Year aneurysm-related complication-free survival	79%	75.6%	.9

study, even though there was no significant difference in early reinterventions (2.9% vs 1.8%; $P = .3$).

The endovascular approach follow-up results were satisfactory, with good survival rates and a limited risk of reintervention at seven years. These findings were similar to those obtained with open surgical treatment, even if a trend toward a higher aneurysm-related complication rate was confirmed (14.5% vs 6.4%; $P = .07$).

Aneurysm behavior and late outcomes. A significant shrinkage of the aneurysmal sac was observed on follow-up, with a decrease in the maximum diameter from 24.8 to18.8 mm ($P < .001$). Piffaretti et al[17] reported excellent long-term results in 30 patients treated endovascularly. However, a significant risk of developing sac reperfusion was noted, especially in cases of bigger aneurysms; this outcome was similarly reported by Cochennec et al.[15] In our experience, only one patient developed late sac reperfusion, without aneurysmal growth. The almost exclusive use of DUS for performing follow-up in this series may have underestimated its incidence; small and low-flow sac reperfusion may have been missed. Furthermore, possible misdiagnosed endoleaks may not have had any clinically relevant consequences, because no ruptures occurred and no reinterventions for sac enlargement were necessary during follow-up.

The main concern regarding the endovascular management of VAAs is the non-negligible rate of late procedure-related complications. Therefore, several authors still recommend open surgery in patients with a long life expectancy and acceptable surgical risks. However, when comparing the follow-up results of our previous series[9] with those of the present study, we did not observe a significant increase in aneurysm-related complication rates over the years. Thus, although the procedure is currently effective in the mid-term, future technological developments may allow further improvements in outcomes, closing the gap between it and open surgery.

Study limitations and strengths. This study has several limitations. It is a retrospective analysis of prospectively collected data including all interventions for VAAs, going through a considerable long period in which the indications for treatment, techniques, and materials have changed and evolved. Owing to the increasing trend of adopting an endovascular-first strategy, the number of open interventions has decreased progressively, making this study's comparison with our historical series the only possible analysis. The number of endovascular interventions was relevant and the follow-up was robust, with significant results up to 7 postoperative years, representing the longest postoperative follow-up reported to date.

CONCLUSIONS

In patients with VAAs, endovascular repair is safe and effective, with a low rate of perioperative complications and several advantages over open repair, owing to the minimal invasiveness of the technique. Follow-up outcomes were satisfactory and comparable with those of our historical series of open surgical repairs. Even if there was a trend toward a higher risk of aneurysm-related complications among patients undergoing endovascular surgery, it does not imply an increased need for late reinterventions. These procedures can be performed endovascularly in the majority of cases. Based on our results, we have been changing our attitude toward patients with VAAs. We reserve open surgical treatment only for patients with lesions unamenable to endovascular repair. Furthermore, the endovascular approach is used whenever possible, independent of patient age, life expectancy, and surgical risk.

AUTHOR CONTRIBUTIONS

Conception and design: AF, WD, RP
Analysis and interpretation: SS, DE, EG, WD
Data collection: RF, BB
Writing the article: RF, SS, WD
Critical revision of the article: AF, BB, DE, EG, RP

Final approval of the article: AF, RF, SS, BB, DE, EG, WD, RP
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