Associated factors, timing, and technical aspects of late failure following open surgical aneurysm repairs

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Objective: **In contrast to endovascular repair (EVAR), the absence of rigorous imaging follow-up after open surgical repair (OSR) has rendered the perception that late failure (LF) is rare. Better understanding of associated factors with LF will help define OSR follow-up paradigms and perhaps alter initial repair strategy to facilitate treatment of LF. The aim of this study is to evaluate aspects of LF requiring intervention after OSR.**

Methods: **From 1998 to 2008, data were collected prospectively on 1097 patients who underwent an aortic endovascular repair. Patients undergoing intervention for LF contiguous with prior OSR were subjected to further analysis. The indication for reintervention was a maximal diameter >60 mm. Univariable and multivariable linear regression models were used to compare patients and disease variables (18 variables regarding age, comorbidities, family history, etiology, and extent) with time to LF.**

Results: **LF of open surgical aneurysm repair was identified in 104 (9.5%) patients. Mean aneurysm diameter was 72 ± 12 mm. Mean age at first repair and time between the two repairs were 61.4 ± 10.0 and 10.8 ± 6.0 years, respectively. When compared with the 993 other patients whose EVAR was their primary repair, LF patients were significantly younger at the time of their first repair (61.4 ± 10.0 vs 74.1 ± 9.6 years; $P < .00001$) and more frequently had a family history of aneurysms (20% vs 7%; $P = .001$). They were also more likely to have presented with dissection, renal insufficiency, and manifestations of atherosclerosis. On multivariable analysis, patients with an initial incomplete OSR (aneurysm located in another aortic segment but not treated at the time of the primary repair), more extensive aneurysms (those involving the descending thoracic or the thoracoabdominal aorta), and older patients experienced earlier LF ($P < .00001$, .002, and .001, respectively). Although we were incapable of determining the incidence of LF after OSR, 34% of patients presenting with LF were regional to our center.**

Conclusion: **Aneurysmal disease is an ongoing process potentially involving the entire aorta. Segments that appear normal prior to OSR of EVAR may be vulnerable to LF. We identified several groups of patients following OSR who mandate more aggressive follow-up given their propensity to present with LF. The threshold and strategies guiding reintervention in the setting of LF is dependent upon many factors relating to the structure and the morphology of the aorta and implanted graft, the type of anastomosis, and patient comorbidities. Therefore, surgeons should consider LF treatment options when planning an aneurysm repair in an effort to optimize any later interventions, and have specifically tailored follow-up paradigms. (J Vasc Surg 2010;52:272-81.)**

The fundamental objective of aortic aneurysm repair is to extend life by preventing aortic-related death. As aneurysmal disease is an evolving process that may involve the entire aorta, failure to identify areas that appear to be of normal caliber yet histologically may harbor evidence of wall weakness may mean that the primary procedure does not treat the full extent of the disease. This leads to treatment failure and recurrent risk of rupture for patients who live long enough. Open surgical repair (OSR) is considered a durable treatment with a low rate of secondary vascular interventions.[1,2] Endovascular repair (EVAR), in comparison, is credited with excellent early results, but the durability has been questioned, and stringent follow-up protocols are required to detect failure.[3,4] This may represent a form of ascertainment bias when compared with historical open controls not typically subjected to regular long-term follow-up.

Material fatigue, incomplete initial treatment, or progression of initially unidentified aortic pathology may all contribute to late failure. Ectasia, thrombus, or irregularities of the vessel wall are frequently noted in contiguity with aneurysms, but the significance of these findings remains unclear. Microscopic disorders can also be present but not detected by preoperative imaging or intraoperative examination. Thus, identification of a normal or abnormal aortic segment is based upon subjective analysis, and repair strategy is a balance between two conflicting options: an aggressive approach that involves the replacement of large lengths of aorta and attached vessels, or a lesser repair with acceptance of a possible LF.

LF after EVAR has been well studied and reflected in the incidence of secondary intervention after primary repair. In contrast, LF after OSR is considered extremely rare. Long-term surveillance paradigms are still debated and

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Table I. Variables analyzed in the present study

Variable	*Definition*
Characteristics of the initial repair (OSR)	
Age at first repair	In years
Etiology of the initial disease	Dissection or other
Extension of the initial OSR	IRAA or DTA/TAAA
Context of the initial OSR	Elective or emergent
Family history of aneurysms	History of aneurysm in a first-degree relative
History of multiple aneurysms repair	Antecedent of at least one previous OSR for aneurysmal aortic disease at the time of the OSR considered in this study
Other untreated aneurysms at the time of the initial OSR	Any other aortic aneurysm (1.5 the normal aortic diameter of the considered segment)
Characteristics of the secondary repair (EVAR)	
Age at second repair	In years
Time between the two repairs	In years
Type of failure	True aneurysm or pseudoaneurysm
Comorbities	
Tobacco use	Any history of tobacco use (including past history)
Hypertension	Any history of hypertension (including controlled hypertension)
Hyperlipidemia	Any history of hyperlipidemia (including controlled hyperlipidemia)
Chronic renal insufficiency	Creatinine $\geq$1.5 μm/L
Chronic obstructive pulmonary disease	FEV1/FVC $\leq$70%
Diabetes mellitus	Any history of type 1 or 2 diabetes (including controlled diabetes)
Coronary artery disease	Any symptom of heart ischemia, antecedent of coronary revascularization, and/or positive stress test
Peripheral artery disease	Any peripheral arterial symptoms resulting from occlusive disease and/or antecedent of limb revascularization

DTA, Descending thoracic aneurysm; *IRAA,* infrarenal aortic aneurysm; *OSR,* open surgical repair; *TAA,* thoracoabdominal aneurysm.

detection of LF is the result of symptoms or coincidence. However, there is evidence that the aorta continues to enlarge in perianastomotic areas,[5] with reports of recurrent aneurysms[6,7] and pseudoaneurysms.[8,9]

Several groups of patients may be at high risk for aneurysm recurrences because of their genotypes, comorbidities, or etiology of aortic disease. On the other hand, an incomplete initial OSR sparing diseased or vulnerable aortic segments likely also contributes. Better understanding of the mechanism, incidence, etiology, and associated factors with LF will help to define follow-up paradigms after OSR and possibly alter the initial repair strategy. This study evaluates the different aspects of LF requiring intervention after OSR through a subset of patients secondarily treated with EVAR in a large referral institution.

MATERIAL AND METHODS

From January 1998 to November 2008, data were collected prospectively on 1097 patients enrolled in one of three physician-sponsored Investigational Device Exemption studies. All underwent an aortic endovascular repair at the Cleveland Clinic Foundation (Cleveland, Ohio) with an infrarenal, a thoracic, or a fenestrated/branched device. All patients were considered at high risk for an OSR based upon physiologic and anatomic characteristics, which have been reported previously.[10] The following devices were implanted: 387 patients received an infrarenal device (Zenith, Cook Inc, Bloomington, Ind), 220 received a thoracic device (TX 1 and 2 devices, Cook Inc), and 490 received a fenestrated or a branched device (Cook Inc). Informed consent, approved by the Institutional Review Board, was obtained for all subjects. Clinical data and imaging were reviewed, and patients who underwent a prior OSR presenting with aneurysmal degeneration in continuity with that repair were selected for analysis.

Inclusion/exclusion criteria. This study included LF after primary OSR and patients were required to meet at least one of the following criteria:

1. Dilatation of the aorta in continuity with the prior repair >60 mm (either proximal or distal) or
2. Pseudoaneurysms of the proximal or distal anastomoses >60 mm.

Patients with noncontiguous aneurysms, suspected infection, fistula, material graft failure, and planned staged procedures were excluded from analysis.

Patient selection. Further assessment of the 213 patients (19.4%) who had undergone an OSR noted 106 who did not match the inclusion criteria, and thus were excluded:

- Fifty-two patients (including 47 elephant trunk completion) had their OSR with a planned staged EVAR,
- Forty-four patients had noncontiguous aneurysms, perhaps unrelated to the OSR,
- Nine patients were technical failures of OSR. They underwent open surgery, but their aortic repair was not completed for various intraoperative reasons (intestinal injury, intraoperative discovery of cirrhosis, hemodynamic instability, nondissectible aneurysm),
- One patient was an early failure of OSR (postoperative anastomotic leak).

Table II. Comparison of patient characteristics between the late failure group and the group of patients whose EVAR was their primary repair

Characteristics	*LF (N,%)*	*Primary EVAR (N, %)*	*Statistical analysis* P *value*		*OR (95% CI)*
			Univariable	*Multivariable*	
Total population	104 (9)	993 (91)	—	—	—
Age at first repair, mean (SD)	61.4 (10.0)	74.1 (9.6)	<.0001	**<.00001**	0.6 (0.5-0.7)
Etiology of the initial disease					
Dissection	12 (12)	35 (4)	<.001	**.002**	1.6 (0.6-3.9)
Others	92 (88)	958 (96)			
Context of the initial repair					
Emergent elective	9 (9)	79 (8)	.8	—	—
	95 (91)	914 (92)			
Family history of aneurysms					
Yes	21 (20)	67 (7)	<.0001	**.001**	2.8 (1.5-5.1)
No	83 (80)	926 (93)			
Age at EVAR, mean (SD)	72.3 (10.6)	74.1 (9.6)	.07	—	—
Gender					
Male/female	86 (83)	755 (76)	.1	.2	1.5 (0.8-2.8)
	18 (17)	238 (24)			
Tobacco use					
Yes	89 (86)	827 (83)	.5	—	—
No	15 (14)	166 (17)			
Hypertension					
Yes	85 (82)	774 (78)	.4	—	—
No	19 (18)	219 (22)			
Chronic renal insufficiency					
Yes	24 (23)	93 (9)	.00001	**.003**	2.4 (1.4-4.3)
No	80 (77)	900 (91)			
Chronic obstructive pulmonary disease					
Yes	37 (36)	348 (35)	.9	—	—
No	67 (64)	645 (65)			
Diabetes mellitus					
Yes	16 (15)	147 (15)	.9	—	—
No	88 (85)	846 (85)			
Coronary artery disease					
Yes	69 (66)	539 (54)	.02	**.05**	1.7 (1.0-2.8)
No	35 (34)	454 (46)			
Peripheral artery disease					
Yes	28 (27)	147 (15)	.001	**.002**	2.3 (1.4-3.9)
No	76 (73)	846 (85)			

CI, 95% confidence interval; *EVAR,* endovascular repair; *LF,* late failure; *OR,* odds ratio.
Variables with a *P* value inferior to 0.2 on univariable analysis were subjected to multivariable analysis.

The 107 remaining patients were further analyzed. In three cases, complete information regarding the extent of the initial OSR was unable to be identified; thus, these patients were excluded.

Data collection. A total of 18 variables regarding the demographics, the characteristics of the initial aortic disease, and the OSR were considered for this study (see Table I for details).

Statistical analysis. Statistical analysis was planned a priori. Continuous variables were described as mean (standard deviation [SD]), and categorical variables as number (%). Time between the open and the endovascular repair followed an approximate normal distribution, so no transformation was necessary. Univariable and multivariable linear regression models were used to model the relationship between clinical/demographic variables and time between open and endovascular repair. Associations from the linear model are given as coefficients, standard errors (SE), and *P* values. These coefficients describe the mean difference of time between categories of given variables. Variables with $P \leq .2$ in the univariable analysis were chosen for the multivariable analysis. In the univariable and the multivariable analysis, variables with $P < .05$ were regarded as significant. All analyses were done using S-Plus 7.0 (TIBCO Spotfire, Somerville, Mass).

RESULTS

Population/demographics. LF contiguous with prior OSR was treated and analyzed in 104/1097 (9.5%) patients (83% male). Aneurysms were identified in a first-degree relative in 21 patients (20%). Other pertinent patient characteristics are found in Tables II and III.

Characteristics of the first OSR. Mean age at first repair was 61.4 ± 10.0 years. Etiology of the aortic disease was nonspecific in 92 of 104 (88%) and dissection in 12 (12%). The OSR was located in the infrarenal abdominal

Table III. Comparison of patients and repair characteristics regarding their time to LF

Characteristic	n (%)	Age at OSR (mean [SD])	Time to LF (mean [SD])	Statistical analysis P value	
				Univariable	Multivariable
Total population	104 (100)	61.4 (10.0)	10.8 (6.0)	—	—
Age at OSR					
Per 5 years, increase	104 (100)	—	—	**.02**	**.001**
Etiology of the aortic disease					
Dissection	12 (12)	53.2 (16.4)	5.3 (3.3)	**.0004**	.2
Other	92 (88)	62.9 (8.1)	11.7 (5.9)		
Extension of the intial OSR					
DTA/TAAA	30 (29)	58.3 (13.3)	6.5 (4.6)	**<.0001**	**.002**
IRAA	74 (71)	62.7 (8.1)	12.6 (5.6)		
Context of the initial OSR					
Emergent	9 (9)	57.6 (17.0)	8.6 (7.0)	.3	—
Elective	95 (91)	61.8 (9.1)	11.1 (5.9)		
Family history of aneurysms					
Yes	21 (20)	59.3 (7.2)	12.1 (5.6)	.3	—
No	83 (80)	61.9 (10.6)	10.5 (6.1)		
History of multiple OSR					
Yes	15 (14)	59.9 (12.8)	10.4 (5.6)	.7	—
No	89 (86)	61.7 (9.5)	10.9 (6.1)		
Other aneurysm(s) at the initial OSR					
Yes	16 (15)	64.0 (13.9)	3.6 (2.6)	**<.00001**	**<.00001**
No	88 (85)	60.9 (9.1)	12.1 (5.5)		
Type of LF					
True aneurysm	90 (87)	61.8 (9.5)	11.1 (6.0)	.5	—
Pseudoaneurysm	14 (13)	59.2 (12.7)	9.4 (6.3)		
Gender					
Male	86 (83)	61.6 (9.9)	11.2 (6.0)	.2	.6
Female	18 (17)	60.7 (10.7)	9.3 (5.8)		
Tobacco use					
Yes	89 (86)	61.3 (9.7)	11.2 (5.8)	.2	.7
No	15 (14)	62.0 (12.1)	8.4 (6.8)		
Hypertension					
Yes	85 (82)	60.9 (9.7)	11.3 (6.0)	.2	.4
No	19 (18)	63.5 (11.3)	8.8 (5.9)		
Hyperlipidemia					
Yes	65 (62)	61.8 (8.1)	11.9 (5.5)	**.02**	.8
No	39 (38)	60.8 (12.6)	9.0 (6.4)		
Chronic renal insufficiency					
Yes	24 (23)	60.5 (10.5)	11.2 (6.6)	.8	—
No	80 (77)	61.7 (9.9)	10.8 (5.8)		
Chronic obstructive pulmonary disease					
Yes	37 (36)	63.4 (7.4)	10.4 (6.4)	.5	—
No	67 (64)	60.3 (11.1)	11.1 (5.8)		
Diabetes					
Yes	16 (15)	59.8 (8.4)	11.3 (4.7)	.8	—
No	88 (85)	61.7 (10.3)	10.8 (6.2)		
Coronary artery disease					
Yes	69 (66)	61.8 (9.2)	11.5 (5.7)	.2	.4
No	35 (34)	60.7 (11.5)	9.6 (6.4)		
Peripheral artery disease					
Yes	28 (27)	62.1 (9.1)	11.8 (6.3)	.2	.09
No	76 (73)	61.2 (10.3)	10.5 (5.9)		

DTA, Descending thoracic aneurysm; *IRAA,* infrarenal aortic aneurysm; *LF,* late failure; *OSR,* open surgical repair; *TAA,* thoracoabdominal aneurysm.
Variables with a *P* value inferior to 0.2 on univariable analysis were subjected to multivariable analysis.

aorta (IRAA) in 74 (71%) and in the descending or the thoracoabdominal aorta (DTA/TAAA) in 30 (29%). Of the 74 patients who underwent an IRAA repair, 42 (40%) had an aorto-aortic repair, 21 (20%) an aorto-bi-iliac repair, and 11 (11%) an aorto-bi-femoral repair. Aneurysmal disease cure was considered incomplete at the time of the OSR in 16 (15%) patients (seven IRAA repairs and nine DTA/TAAA repairs), when other aneurysms were apparent but did not reach a size prompting extension of the OSR into that bed. Nine of the initial repairs (9%) were performed in emergency for rupture and/or symptomatic aneurysms. Three (3%) aneurysms were considered inflammatory. When compared with the 993 other patients (368 IRAA repairs, 203 DTA repairs, and 422 fenestrated/branched repairs), the 104 LF patients were significantly younger at the time of their first repair (61.4 ± 10.0 vs 74.1 ± 9.6 years; $P < .00001$) and were more likely to have a family history of aneurysms (20% vs 7%; $P = .001$). They also presented with more general manifestations of cardiovascular disease such as coronary artery disease (CAD; 66% vs 54%; $P = .05$) and peripheral artery disease (PAD; 27% vs 15%; $P = .002$), a greater proportion of dissections (12% vs 4%; $P = .002$), and chronic renal insufficiency (CRI; 23% vs 9%; $P = .003$). These findings are summarized in Table II.

Characteristics of the late failures. Mean age at second repair and time between the two repairs were 72.3 ± 10.6 and 10.8 ± 6.0 years, respectively. The mean aneurysm diameter at the time of the second repair was 72 ± 12 mm, and 10 (10%) were symptomatic and/or ruptured. The LF were de novo contiguous aneurysms in 90 cases (87%) and anastomotic pseudoaneurysms in 14 cases (13%). Thirty-two (31%) presented two different types of LF, including 30 (29%) patients with failure of both the proximal and ends of the repair. Seventy-six patients (73%) presented with LF located above their previous OSR, while 24 (23%) developed their new dilatation below. The remaining four patients (4%) presented with visceral patch aneurysms after a thoracoabdominal repair. The treatment of LF required 19 infrarenal, 13 thoracic, and 72 fenestrated/branched repairs.

Statistical analysis — time to LF. Using univariable analysis, factors significantly associated with an earlier time to LF are found in Table III and include an incomplete initial OSR (3.6 ± 2.6 vs 12.1 ± 5.5; $P < .00001$), patients operated on for a dissection (5.3 ± 3.3 vs 11.7 ± 5.9 years; $P = .0004$), a more proximal disease (6.5 ± 4.6 for DTA/TAAA vs 12.6 ± 5.6 years for IRAA; $P < .0001$), an older age at OSR (per 5 years, increase; $P = .02$), and presence of hyperlipidemia (9.0 ± 6.4 vs 11.9 ± 5.5 years; $P = .02$). Five additional variables with a P value ≤.2 (gender, smoking history, hypertension history, presence of coronary artery disease, presence of peripheral artery occlusive disease) were subjected to multivariable analysis.

After multivariable analysis, three variables were found to be independently associated with an earlier LF. These factors were an incomplete initial OSR ($P < .00001$), an older age at open repair (per 5 years, increase; $P = .001$), and a more proximal disease ($P = .002$). There was also a trend for an association between peripheral arterial occlusive disease and earlier LF, but this was not significant ($P = .09$). Dissections were not associated with early failure; however, 5 of the 12 patients with dissection had an incomplete OSR.

DISCUSSION

Any aortic repair has a potential risk of LF because of degradation of graft material or progression of disease in what was perceived to be a normal-caliber aorta or iliac vessel. In this study, we analyzed the population of patients in which endovascular methods were used to rescue failing OSR. Although LF can have many forms, including limb thrombosis, graft degeneration, and infection, we focused

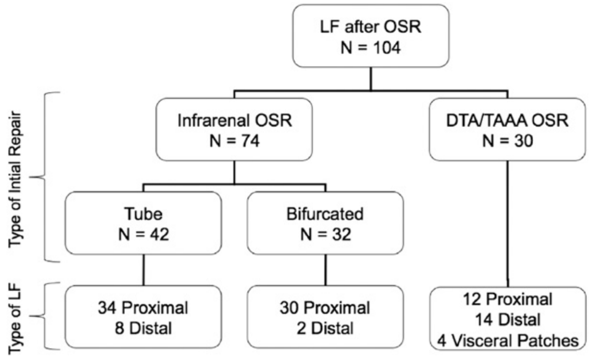

Fig 1. Types of late failure (LF) following open surgical repairs of the 104 patients included in this study.

on aneurysmal degeneration requiring reoperation as the subject of this article. When others[1,2,11-14] tried to determine the durability of OSR, they also ignored some aspects of LF, used nonstandard imaging methods, or reported insufficient follow-up durations when compared with the mean time to LF found in the present study. The main reason is that, until recently, there has been no defined follow-up paradigm for OSR. In the current practice, the detection of LF is often the result of coincidence (during radiographic evaluations and/or other issues) or symptoms, and this was the case for the large majority of our patients. Therefore, we cannot define the incidence of LF as we serve as a referral center for complex cases. Overall, 35 of our patients (34%) resided in Ohio, and only nine (8%) underwent their initial repair at our institution. In addition, we did not evaluate other factors that may contribute to a need for reintervention following OSR, such as hernias or bowel obstructions. These issues underscore the importance of characterizing LF in an effort to determine follow-up paradigms and treatment strategies for patients following OSR.

We identified the profiles of patients with LF and those susceptible of an earlier failure. The statistical analysis comparing LF patients with others was conducted at a certain point of time; therefore, we cannot exclude the idea that an unknown proportion of our control group will also experience LF during the following years and perhaps alter our conclusions. However, although suffering from the biases of a retrospective study, our results emphasize the idea that patients are not equal in their risk for LF and give some indications about subgroups that would need to be investigated in further prospective studies. Our multivariable analysis demonstrated that several factors were associated with LF (younger age, family history of aneurysms, dissections, diffuse atherosclerotic disease, and CRI) while other groups of patients experienced earlier LF (incomplete initial OSR, older age, and extensive disease). Although younger patients were more vulnerable to LF, older patients at the time of the OSR experienced earlier LF. These findings could be explained by the fact that young patients at the time of the initial OSR have a life expectancy superior

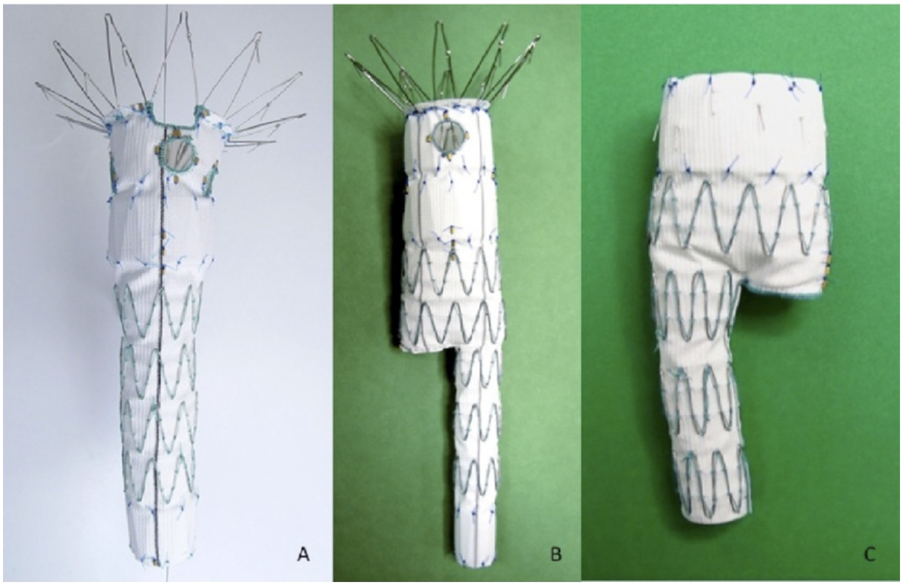

Fig 2. Examples of endografts used to treat late failure above prior infrarenal repairs. When the distance between the lowest renal artery and the bifurcation is long, the insertion of a standard fenestrated component is possible **(A)**. If this distance is short, an older version of fenestrated graft made of a unique bifurcated component including fenestrations can be implanted **(B)**. When the distance between the lowest renal artery and the bifurcation is short but allows for the implantation of two components, a bifurcated component with an internal limb can be used **(C)**. In such cases, due to the limited overlap, a fixation mechanism using barbs can be added at the proximal stent of the bifurcated component, or the contralateral limb overlap section can reside within the aortic tubular component, termed an "internal limb".

to the durability of their first repair, while older patients could be the victims of more limited initial OSR sparing borderline aortic segments to decrease the operative risk. Therefore, the latter method of surgical repair would result in the conservation of residual aortic disease and thus experience faster degeneration.

The perception of durability attributed to open repair may be due to the lack of standardized and protocolized imaging follow-up in historical series. OSR for IRAA is reported to be associated with fewer late aortic-related interventions[3] and remains considered as the gold standard. However, 26% of survivors undergo at least one vascular intervention after 15 years.[1] In this perspective, the treatment of an IRAA at a certain point of time is not synonymous with definitive cure of the disease. OSR may postpone the time to LF when compared with EVAR, but remains at risk to fail. This raises the question as to whether aneurysm repair in any context is palliative or curative. In our study, LF occurred 12.6 ± 5.6 years after IRAA repair, and 85% (64/74 patients) of the failures were located above the OSR. Although our recruitment might have been biased by our expertise in fenestrated and branched devices, these types of LF were comparable to what was reported in prospective reports[15] and were associated with reinterventions.[7,13,16] Our study is a retrospective analysis of prospectively collected data regarding LF after OSR treated using EVAR. Therefore, it can only allow for tentative conclusions regarding follow-up paradigms after OSR. However, due to the late occurrence of treatment failure, it is now our practice to perform lifetime aortic imaging follow-up after primary OSR. Our approach has been similar to the recent SVS guidelines,[17] which recommend computed tomography (CT) follow-up at a minimum of 5-year intervals after OSR for IRAA.

Greater extent of aortic repair (DTA/TAAA) and concurrent disease predict earlier failure, suggesting that the failure mode may lie in unrecognized disease or vulnerable aorta. Following OSR for TAAA, Clouse et al[8] found a 10.8% event rate after a 26-month follow-up, including 73% related to the native aorta. In our study, 9 of the 30 (30%) patients with initial DTA/TAAA repair presented with other significant dilatations of the aorta at the time of the OSR, and irregularities, thrombus, and/or ectasia are frequently noted in other aortic zones while planning the repair. However, we were not able to determine the clinical relevance of such findings for our practice since morphologic follow-up studies of extensive aneurysms are lacking. The identification of aortic segments at risk to degenerate faster could decrease the risk of LF with the price of a more aggressive initial treatment. However, should the repair be more extensive, it may be associated with increasing rates of mortality and morbidity.[18] Therefore, patients operated for a DTA/TAAA should be considered to have a fast progressing disease, and their remaining native aortic segments should be reimaged at least yearly following an OSR.

Since patients are 10 years older, the aortic disease is more extensive, and a higher rate of comorbidities is present in patients referred for LF, EVAR was generally the

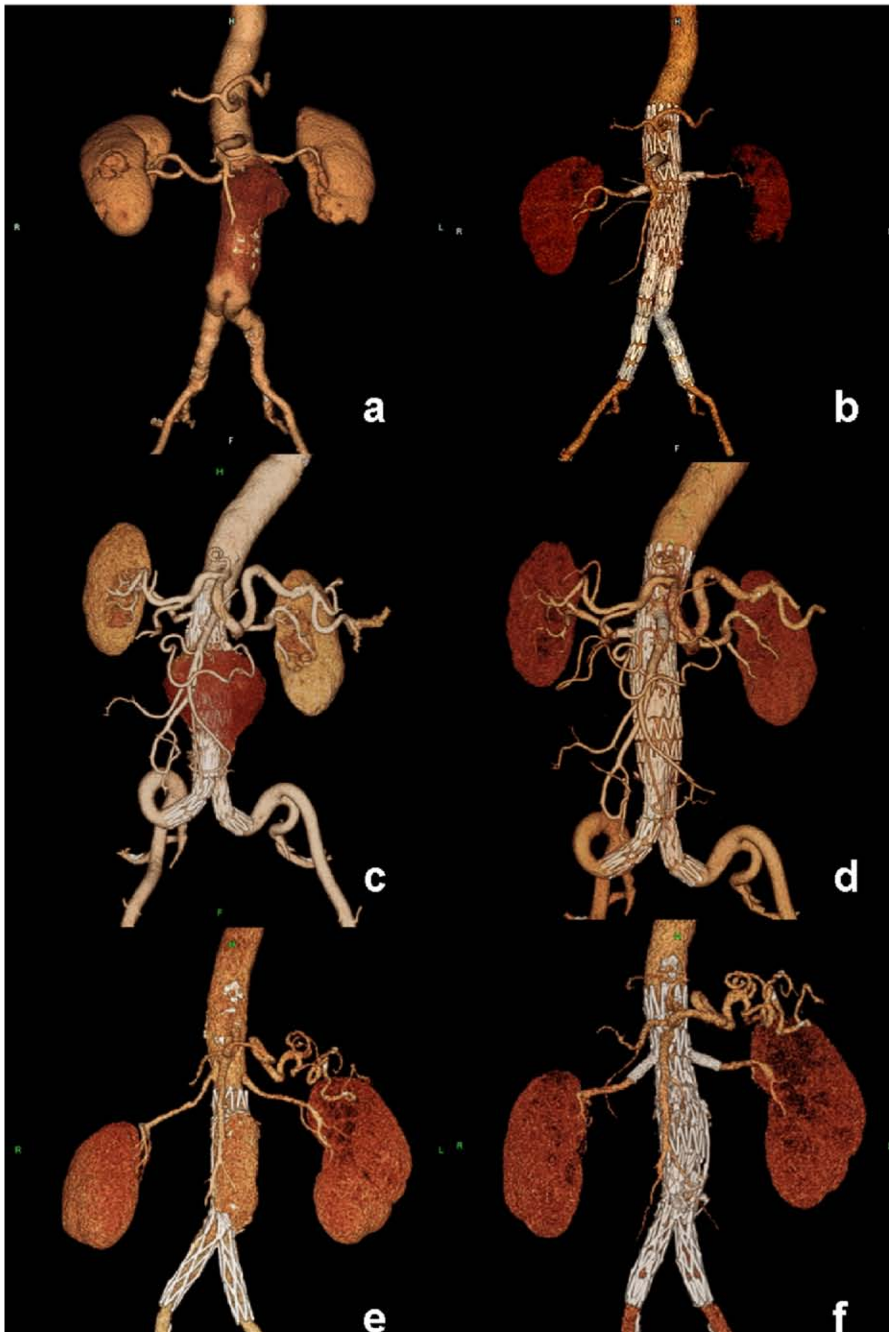

Fig 3. Late failures above bifurcated grafts with long main body. When the distance between the lowest renal artery and the graft bifurcation is long, a standard fenestrated device made of two components can be implanted **(a, b)**. This strategy is similar to the one we used to treat a late failure above a Zenith **(c, d)** or a Powerlink **(e, f)** endograft.

treatment of choice for the secondary procedure.[19] The application of EVAR as a rescue procedure to treat LF can be greatly simplified by modifying the initial OSR in anticipation of the potential for LF. This may consequently alter the configuration and technique of OSR in patients at risk:

- First, the primary repair will optimally allow the planning for late EVAR: the excessive use of metallic material (surgical clips) can create artifact on subsequent imaging, resulting in CT scans that are difficult to interpret.
- Second, the OSR should be planned to facilitate the introduction, deployment, and sealing of a further

Fig 4. Late failures above bifurcated grafts with short main body are much more challenging to treat with an endovascular approach. When the distance between the lowest renal artery and the bifurcation is short but allows for the placement of two components **(a)**, a standard fenestrated device can be inserted, but the bifurcated component is customized and incorporates a contralateral inverted limb **(b)**. When this distance is so short that the insertion of two components is not possible **(c)**, an old version of fenestrated graft (unique component with fenestrations) with an inverted limb can be inserted **(d)**. Proximal late failures of infrarenal endografts with short main bodies present similar issues to those described after a conventional repair. Here is illustrated a proximal failure of an AneuRx endograft **(e)**. This patient was treated using a proximal customized fenestrated component associated with an aorto-uni-iliac endograft, requiring a femoral-femoral bypass.

endovascular device. End-to-end anastomoses of sufficiently-sized prostheses are optimal.

- Furthermore, the length of the tubular component of the repair should be as long as possible (preferably >7 cm) to allow for a proper landing zone above the aortic bifurcation within the old graft. In our experience, the proximal portion in a short, old infrarenal graft serving as a distal landing zone for an EVAR caused frequent issues. This concerned 64 patients of the present series (Fig 1). Following an aorto-aortic tube graft, the distal sealing of a fenestrated or branched endograft was easily achieved within the old tube graft.

Degenerations above short bifurcated grafts result in most challenging cases.[19-22] Most frequently, the complicating factor related to a tubular portion that was quite short, resulting in a short distance between the renal arteries and artificially-raised aortic bifurcation. This resulted in greater challenges in trying to place fenestrations or branches in proximity to a graft bifurcation (they are more easily positioned in the tubular component of a fenestrated/branched graft). Thus, a longer tubular body length will drastically simplify later procedures, given that endovascular devices are made of two abdominal components whose complete design has been described elsewhere.[23] Consequently, when the distance between the lowest renal and the bifurcation is shorter than 36 mm, the use of current classical fenestrated devices is difficult and mandates an older version of fenestrated grafts (a one-piece customized bifurcated component that includes the fenestrations or branches) or specific customization using short fenestrated components with an internal contralateral limb (Fig 2). When the distance between the lowest renal artery and the bifurcation ranges from 36 to 76 mm, the insertion of two components is possible with a correct overlap, but the distal device must be modified into an aorto-uni-iliac graft or a bifurcated component with internal limbs simply to secure the new graft adequately within the old repair. Finally, when the distance is greater than 76 mm, the use of current fenestrated devices is possible without major modification (Fig 3). Therefore, we emphasize the importance of leaving a long tubular section when performing OSR, understandably taking care to shorten the limbs so as not to increase the incidence of limb thrombosis as the graft morphology changes.

Lessons learned from LF of OSR may also help refine the strategy for primary EVAR in patients at risk for LF. Assuming the fact that the natural history of native aortic segments after OSR is not dependent upon the type of repair, patients identified at high risk for LF in this study would have experienced an earlier failure if EVAR was used as primary repair. Enlargement of the proximal or the distal fixation seal in the setting of aneurysmal disease extension is a well-known cause of migration, component separation, and type I endoleak. Therefore, the type of endovascular graft chosen for a primary repair should also take into consideration the possibility of LF in patients at risk. Fixation with endovascular devices should be maximized, as should joint stability. The configuration of an infrarenal EVAR is similar to a bifurcated surgical graft, and we encountered the same technical issues when repairing a proximal failure above a short main body endograft (Vanguard [Boston Scientific, Natick, Mass], AneuRx [Medtronic, Santa Rosa, Calif], Excluder [W.L. Gore, Flagstaff, Ariz]; Fig 4). When planning a repair in patients at high risk for LF, endografts with long main body should be preferred to provide a distal seal for further fenestrated component (Fig 4).

CONCLUSION

Aneurysmal disease is an ongoing process involving the entire aorta. Segments that appear normal during OSR may be vulnerable to LF. LF patients were more likely to be younger at the time of their OSR, have a family history of aneurysms, be atherosclerotic, have aortic dissection, and suffer from chronic renal insufficiency. A faster progressing disease and subsequent earlier failure was related to an incomplete OSR, a more extensive initial disease, and age. However, the threshold for reintervention is dependent upon the stability of a surgically constructed anastomosis, while an endovascular seal may dictate a need for an even earlier treatment. Therefore, subsets of patients identified in this study should always undergo treatment with an initial strategy optimizing any later interventions and require meticulous follow-up for extended periods of time.

AUTHOR CONTRIBUTIONS

Conception and design: RC, RG
Analysis and interpretation: RC, RG, TM
Data collection: RC, WK, CM
Writing the article: RC, RG, TM
Critical revision of the article: RC, RG, TM, ME
Final approval of the article: RC, RG, TM, ME, WK, CM, AH
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