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Natural History of Gutter-Related Type Ia Endoleaks after Snorkel/Chimney EVAR

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Abstract

Objective—Alternative endovascular strategies utilizing parallel or snorkel/chimney (ch-EVAR) techniques have been developed to address the lack of widespread availability and manufacturing limitations with branched/fenestrated aortic devices for the treatment of complex abdominal aortic aneurysms. Despite high technical success and mid-term patency of snorkel stent configurations, concerns remain regarding the perceived increased incidence of early gutter-related type Ia endoleaks. We aimed to evaluate the incidence and natural history of gutter-related type Ia endoleaks following ch-EVAR.

Methods—Review of medical records and available imaging studies, including completion angiography and serial computed tomographic angiography, was performed for all patients undergoing ch-EVAR at our institution between September 2009 and January 2015. Only procedures involving ≥1 renal artery with or without visceral snorkel stents were included. Primary outcomes of the study were presence and persistence or resolution of early gutter-related type Ia endoleak. Secondary outcomes included aneurysm sac shrinkage and need for secondary intervention related to the presence of type Ia gutter endoleak.

Results—Sixty patients (mean age, 75.8 ± 7.6 years; male, 70.0%) underwent ch-EVAR with a total of 111 snorkel stents (97 renal [33 bilateral renal], 12 SMA, 2 celiac). A median of 2 (range, 1-4) snorkel stents were placed per patient. Early gutter-related type Ia endoleaks were noted on 30.0% (n=18) of initial postoperative imaging studies. Follow-up imaging revealed spontaneous resolution of these gutter endoleaks in 47.3% and 71.8% of patients at 6- and 12 months post-procedure, respectively. Long-term anticoagulation, degree of oversizing, stent type and diameter, and other clinical/anatomic variables were not significantly associated with presence of gutter endoleaks. Two patients (3.3%) required secondary intervention related to persistent gutter endoleak. At a mean radiologic follow-up of 20.1 months, no difference in mean aneurysm sac size change was observed between those with or without early type Ia gutter endoleak (−6.1 ± 10.0-mm vs. −4.9 ± 11.5-mm, P=.23).

Conclusions—Gutter-related type Ia endoleaks represent a relatively frequent early occurrence after ch-EVAR, but appears to resolve spontaneously in the majority of cases during early to mid-

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term follow-up. Given that few ch-EVAR patients require re-intervention related to gutter endoleaks and the presence of such endoleak did not correlate to increased risk for aneurysm sac growth, its natural history may be more benign than originally expected.

INTRODUCTION

Originally described by Greenberg et al,[1] the snorkel/chimney technique (ch-EVAR) was first employed as an endovascular aneurysm repair (EVAR) bailout procedure using balloon-expandable bare metal stents to maintain renal patency during deployment of aortic main body devices in very close proximity to the renal ostia. Increasing operator experience led to technical refinement and a growing appreciation for an adequate proximal seal zone. The conceptual basis for ch-EVAR involves deployment of one or more stent grafts parallel to the main aortic endograft to generate cranial extension of the proximal seal zone with preservation of branch vessels, thereby providing an alternative treatment for patients with hostile neck anatomy or inadequate infrarenal neck length.

Until recently, available outcomes from ch-EVAR procedures have been limited to small single center series.[2–6] In 2015, however, Donas and Lee[7] published results from the PERICLES registry, the largest worldwide ch-EVAR experience featuring a total of 898 snorkel stents placed in 517 patients, resulting in a technical success rate of 97.1%, elective thirty-day mortality of 3.6%, and primary branch vessel patency of 94% at a mean follow-up of 17.1 months.

Despite encouraging early and mid-term outcomes, concerns remain regarding the durability of ch-EVAR vis-à-vis fenestrated or branched repair. The oft-debated issue regarding the inevitable formation of so-called “gutters” between the parallel and main aortic stent-grafts, specifically as it relates to the potential for compromised proximal seal and insufficient aneurysm sac exclusion, appears justified given variability in the reported incidence of post-procedural type Ia endoleaks and uncertainty regarding their ultimate clinical relevance. Indeed, type Ia endoleak is frequently regarded as the Achilles heel of parallel graft strategies. The objective of this current study is to evaluate the incidence and natural history of early gutter-related type Ia endoleaks following ch-EVAR.

METHODS

Study population

Between September 2009 and January 2015, all patients treated for complex AAAs utilizing an endovascular parallel graft strategy at a single institution were enrolled in a prospective observational cohort study approved by our local Institutional Review Board. Informed consent was obtained from all study participants. All patients were deemed high-risk for open aortic reconstruction and considered anatomically unsuitable for conventional EVAR with a standard infrarenal stent graft. Only procedures involving one or more renal artery snorkel stents, alone or in combination with visceral snorkel stents, were included in this analysis. Ch-EVAR procedures utilizing a fenestrated proximal main body and/or periscope stent configuration were included only if the aforementioned inclusion criterion involving presence of one or more concomitant renal snorkel stents was met. Patient demographics, serial radiographic imaging studies, procedural metrics, and clinical outcomes were collected and retrospectively analyzed.

Definitions

Gutter-related type Ia endoleak was defined as the persistence of a peri-graft channel of blood flow between the parallel snorkel stent(s) and intra-aortic main body endograft at the proximal attachment zone as a result of inadequate seal. These proximal endoleaks were considered gutter-associated since they persisted despite creation of a >10-mm proximal seal zone. Early type Ia endoleaks included those detected on contrast-enhanced cross-sectional imaging obtained within 30 days of the procedure. Gutter endoleaks were arbitrarily classified as either short or long based on degree of caudal extension of the proximal endoleak relative to the aneurysm sac: short gutter endoleaks were confined to the perigraft channel or terminated within 10-mm of the most inferior snorkel stent, whereas long gutter endoleaks extended >10-mm below the most inferior snorkel stent and/or extended into the aneurysm sac. Type Ia endoleak-associated secondary procedures were defined as re-interventions due to the persistence of a gutter-related type Ia endoleak in combination with >5-mm aneurysm sac diameter growth confirmed by angiography. Aneurysm sac diameters were considered stable if <5-mm of growth was noted on postoperative surveillance imaging.

Outcome measures

Primary outcome measures included incidence and natural history of early gutter-related type Ia endoleak following ch-EVAR, specifically as it relates to either spontaneous resolution or persistence of gutter endoleak on postoperative surveillance imaging studies. Secondary outcome measures included early gutter-related type 1a endoleak-associated re-interventions, aneurysm sac diameter regression, as well as morbidity and mortality.

Snorkel/chimney EVAR technique

All procedures were performed in our hybrid endovascular suite with a fixed floor-mounted imaging Artis zee system (Siemens Medical Solutions USA, Malvern, PA). No devices were modified before implantation. We planned for a minimum of 10-mm of non-diseased neck and placed snorkel stents in single renal, bilateral renal, or, when necessary, superior mesenteric artery (SMA)/celiac branches to maintain adequate proximal seal. When more than two snorkel stents were required, we used either a sandwich strategy with stacked endograft cuffs and a maximum of two snorkel stents in a particular plane or the periscope configuration with downward pointing parallel endografts to provide additional branch preservation. In our more recent experience, the snorkel approach has been used as an adjunct in select fenestrated cases where challenging renovisceral anatomy cannot be fully accounted for by current Food and Drug Administration-approved customized fenestrated devices (e.g. a renal artery with origin at a similar level as the SMA) or severe downward renal angulation that limits cannulation from a transfemoral approach.

Our standardized technique for ch-EVAR has been previously described.[2] Briefly, ch-EVAR was performed by a two-surgeon team working from the right femoral and left axillary positions. Antegrade renal/visceral access is obtained from open exposure of the left axillary or proximal brachial artery. Using the transbrachial approach, target branch vessels are catheterized using 260-cm long hydrophilic guidewires and a shaped catheter. Balloon-expandable covered iCAST stents (Atrium Medical, Hudson, NJ) or Viabahn low-profile self-expanding covered stents (W.L. Gore and Associates, Flagstaff, AZ) are advanced into the target branch vessel as dictated by the tortuosity of the proximal branch vessel and its axis with the aorta. The standard main body endograft is deployed below the most proximal target vessel not being stented. A deliberate sequence of deployment and balloon molding is subsequently performed in a “triple kissing” fashion to optimize theoretical seal and minimize the potential for “gutter” channels at the junction of the snorkel stents and main body endograft.

Clinical follow-up included physical examination with serum creatinine level and computed tomographic angiography (CT-A) within 1 month of the procedure, as well as at six months, one year, and annually thereafter. Detection of a new late type Ia endoleak or presence of any type of endoleak associated with aneurysm sac enlargement greater than 5-mm prompted more frequent surveillance intervals.

Statistical analysis

Descriptive statistics were used to assess patient demographics, comorbidities and clinical outcome variables as appropriate. Wilcoxon rank-sum tests and Pearson chi-squared tests were used to evaluate for potential associations between clinical end-points and continuous and categorical variables, respectively. A Kaplan-Meier cumulative failure function was used to estimate spontaneous resolution of early gutter-related type Ia endoleaks over time. Potential univariate and multivariate predictors of spontaneous resolution of type Ia endoleak were identified by means of Cox proportional hazard models. A $P<.05$ was considered statistically significant for all analyses. Statistical calculations were performed in Stata 12.0 (Statacorp LP, College Station, TX).

RESULTS

Sixty patients (70% male; mean age, 75.8 ± 7.6 years) underwent ch-EVAR during the study period. Demographics of the study population are reported in Table I. Indications for ch-EVAR included short-neck infrarenal AAA in 24 patients, de novo juxtarenal AAA in 17 patients, migration of a previously placed aortic endograft resulting in a type Ia endoleak in 11 patients, para-anastomotic aneurysm following prior open aortic reconstruction in 5 patients, suprarenal AAA in two patients, and type IV thoracoabdominal aneurysm in one patient. The majority of procedures (n=53 [88.3%]) were performed electively; however, 13.2% of cases were performed urgently/emergently due to rapid aneurysmal growth (n=6) or presence of symptoms (n=1).

Anatomic and procedural data are demonstrated in Table II. Median infrarenal neck length and diameter was 0.5-mm (range, 0-9-mm) and 29.5-mm (range, 15-58-mm), respectively. Utilization of a snorkel approach created a new median suprarenal neck length and diameter of 20.0-mm (range, 10-42-mm) and 25.0-mm (range, 18-32-mm), respectively. Aortic main body grafts included 25 (41.7%) Zenith bifurcated systems (Cook Medical, Bloomington, IN), 12 (20.0%) Zenith fenestrated devices (ZFEN [Cook Medical]), nine (15.0%) Renu proximal cuffs (Cook Medical), eight (13.3%) Endurant (Medtronic Vascular, Santa Rosa, CA), two (3.3%) Excluder (W. L. Gore, Flagstaff, AZ), two (3.3%) Ovation (Endologix, Santa Rosa, CA), one (1.7%) Talent (Medtronic AVE), and one (1.7%) TX2 (Cook Medical). A total of 111 snorkel stents were placed (median 2 stents/patient; range, 1-4), which included unilateral renal snorkels in 14 patients, bilateral renal snorkels in 33 patients (including 1 renal snorkel combined with 1 renal periscope), and celiac/SMA/renal combinations in 13 patients (including 1 renal periscope combined with 2 snorkels). Balloon-expandable covered stents (64.5%) served as the preferred snorkel stent graft for target vessel reconstruction compared to self-expanding covered stents (34.5%). When used, the majority of self-expanding covered stents (68.4%) were reinforced with bare metal stents in the portion adjacent to the main body endograft. Mean radiologic follow-up was 20.1 ± 21.0 months.

Gutter-related type Ia endoleak

Twenty-one (35.0%) gutter-related type Ia endoleaks were noted on completion angiography despite attempted corrective maneuvers intraoperatively (e.g. repeat kissing balloon technique). Seven of these angiographically-determined gutter endoleaks resolved spontaneously and were not seen on initial postoperative imaging. In total, 18 gutter-related type Ia endoleaks were noted on first postoperative CT-A (30.0%), including four patients who had no identifiable endoleak on completion angiogram. One-half of these gutter endoleaks detected on CT-A extended into the aneurysm sac and were classified as long (n=9; Fig 1), whereas the remaining half were deemed short (n=9; Fig 2). Type II endoleaks were also noted in 12 (20%) patients on initial postoperative imaging, with one-half of these patients having concomitant type Ia endoleaks. Eleven of the 18 (61.1%) early type Ia endoleaks resolved by latest follow-up imaging without need for re-intervention. Kaplan-Meier analysis determined the estimated spontaneous resolution rate of early gutter-related type 1a endoleaks to be 47.3% and 71.8% at 6- and 12 months post-procedure, respectively (Figure 3A). There was no significant difference in the rate of spontaneous resolution of gutter-related endoleaks when stratified by short versus long (Figure 3B). Aneurysm type, baseline anticoagulation usage, degree of main body oversizing, new neck length, number of snorkel stents, stent type and diameter, snorkel configuration (parallel vs. crossed), neck thrombus and calcification, and other clinical/anatomic variables were not significantly associated with early type Ia endoleaks on multivariate analysis.

The early gutter-related type Ia endoleak-associated re-intervention rate was 3.3%, representing only two of the 60 patients in the overall cohort undergoing ch-EVAR. The first patient represented the only endovascular repair in this cohort utilizing the sandwich technique with four snorkel stent configuration to exclude a 6.2-cm type IV thoracoabdominal aortic aneurysm. Due to presence of type Ia endoleak and progressive aneurysm sac expansion (>5-mm) noted on serial postoperative imaging, he underwent successful proximal cuff placement and neck “lengthening” with extensions to his previously placed celiac and SMA snorkel stents seven months postoperatively. Subsequent imaging noted stability in aneurysm sac size and interval improvement but persistent small gutter endoleak. In addition, we counted a second patient who requires secondary intervention due to progressive aneurysm sac growth up to 8.3-cm from a preoperative sac size of 7.3-cm noted within nine months of undergoing ch-EVAR with a single renal snorkel stent and the Ovation device. The patient suffered an unrelated type A aortic dissection during the follow-up period and endovascular re-intervention to address the type Ia endoleak is currently pending improvement in his tenous health status after open ascending aortic repair.

Aneurysm sac regression

Mean aneurysm sac regression for the entire cohort at latest follow-up was 5.3 ± 11.0-mm and was not significantly different based on presence or absence of early gutter-related type Ia endoleak (P=.70, Table III). While preoperative and follow-up aneurysm sac size was similar between those with and without type Ia endoleaks, significant sac regression after ch-EVAR was achieved in both groups relative to their respective preoperative measurements. Aneurysm sac growth of any degree on follow-up imaging was not significantly different between groups, occurring in 5 patients (11.9%) without early type Ia endoleak (>5-mm growth, n=2) and in three patients (16.7%) with early type Ia endoleak (all >5-mm growth). Of the three patients with sac expansion in the setting of type Ia endoleak, one expired four months postoperatively from a myocardial infarction, one is awaiting secondary intervention as detailed earlier, and one was noted to have spontaneous resolution on surveillance imaging. The two patients with sac expansion in absence of early type Ia endoleak included the single patient with late type Ia endoleak development who underwent attempted secondary intervention, as well as a patient who underwent successful embolization of a type II endoleak and later sac regression on follow-up imaging. No differences in sac behavior or other clinical outcomes were noted between short and long type Ia gutter endoleaks (Table IV).

Mortality and morbidity

Two patients died within thirty days of the procedure (3.3%), both early in our ch-EVAR experience. One death occurred in a patient who received bilateral renal snorkels and was readmitted one week postoperatively with pneumonia and ultimately died due to sepsis. The other early death occurred in a patient who underwent triple snorkel stent placement requiring bilateral axillary access, which was complicated by iliac rupture prompting need for an endoconduit. This patient awoke with a moderate right hemispheric stroke that progressed over five days to a hemorrhagic infarct. The family elected comfort care measures and she expired. Postoperative imaging in both of these patients demonstrated successful endovascular exclusion of juxtarenal aneurysms and patent snorkel stents. Periprocedural morbidity included non-ST elevation myocardial infarction in three patients and decompensated congestive heart failure in one patient. No coronary revascularization was required in any of these patients. At a mean clinical follow-up of 26.9 ± 19.1 months, there have been five additional late deaths of cardiac origin. No late aneurysm-related deaths have been recorded.

DISCUSSION

As noted in a prior meta-analysis,[8] it appears paradoxical, whether intuitively or geometrically, that a parallel series of cylindrical tubes (representing the snorkel/chimney and main aortic endografts) positioned within a larger non-uniform cylinder (representing the native aorta) can direct systemic arterial blood flow exclusively through the lumen of the stent grafts and not into the perigraft channels, or gutters, that inevitably form between the grafts and the aortic wall. Nevertheless, the efficacy of the snorkel/chimney approach in EVAR has been demonstrated in multiple early experiences[2–5] and, more recently, corroborated by two large multi-institutional studies.[7,9] Despite increasing popularity and high technical success noted in these reports, the perceived increased incidence of early gutter-related type Ia endoleaks using the snorkel approach remains the primary criticism of this technique. To further inform the debate, the present report is the first to provide a dedicated analysis on the natural history of gutter-related type Ia endoleaks after ch-EVAR.

There is significant variability in the literature with regards to reporting of both the timing and mode of detection of gutter-related type Ia endoleaks following ch-EVAR. Our early gutter-related type 1a endoleak rate of 30% is consistent with the 0% to 37.5% rate noted in previous reports.[2–9] Some of these reports include only those gutter endoleaks noted on completion angiography, whereas others note only those detected on the initial post-procedural cross-sectional imaging study. Others report the aggregate sum of proximal endoleaks of any severity identified on one of two complementary imaging modalities at any point along the entire thirty-day perioperative period. We feel that completion angiography may not provide an accurate reflection of true gutter endoleaks as they may be transient as a result of intraoperative blood pressure fluctuations, systemic anticoagulation, or difficult to differentiate from a slow type II endoleak. Publication bias, and the fact that over three-fourths of our cases required two or more snorkel stents, may also have contributed to our increased gutter endoleak rate compared to other published series. We also did not discriminate between those oft-described delayed, small volume (e.g. “low flow”), or “short” endoleaks and the more rapid, large volume (e.g. “high flow”), or “long” type Ia gutter endoleaks. Comparison across studies is admittedly limited by nonstandardized protocols and a heterogenous mix of both aneurysm morphologies and devices used.

Despite the relatively common occurrence of early gutter-related type Ia endoleaks in our study, 61.1% resolved spontaneously over the follow-up period without the need for re-intervention. The first 12 months post-procedure was marked by the greatest rate of spontaneous resolution, increasing from 47.3% at six-months to 71.8% at one-year. Similar observations of early spontaneous resolution have been noted in other series.[5,6,10] It has been proposed that interaction of blood with the graft and elastic deformation of the native aorta at the proximal seal zone, combined with a local relative decrease in velocity and increase in blood viscosity, predisposes to progressive thrombus formation in the gutters between adjacent parallel stent grafts.[8] Such a mechanism supports the general belief that likelihood of spontaneous resolution of flow in the gutter is proportional to the length and inversely proportional to the cross-sectional area of the gutter.

Since case planning and stent graft conformability is geared toward minimizing the area of potential gutters, type Ia endoleaks in ch-EVAR are commonly low-flow and, unlike proximal endoleaks in other endovascular repairs, often do not require re-intervention. Interestingly, we noted no difference in the rate of spontaneous resolution of early type Ia endoleaks between our described short and long type Ia gutter endoleaks. In a meta-analysis by Wilson et al,[11] which evaluated 234 patients from 24 studies, only five type Ia endoleaks (not classified by diameter, length, or volume) were treated among the 13 originally diagnosed at a mean follow-up of 12.1 months.

The presumed multifactorial mechanism of proximal seal in ch-EVAR has centered primarily on the interactions between the snorkel/chimney graft, main aortic stent graft, and native aorta. To that end, a variety of both anatomic and procedural factors have been postulated to predispose to type Ia endoleak. Aortic rigidity secondary to dense calcification or thrombus burden, for example, may inhibit localized deformation of the aortic wall and optimal conformability around the snorkel stents. Neither of these factors played a dominant role in our analysis. In theory, an increased number of chimney grafts outside the main aortic stent graft yields increased gutters and a corresponding increased risk for proximal endoleak, but this has not been verified in any study thus far.

Recognizing that resistance to flow is proportional to the length of the perigraft flow channel, the length of the “new” neck created by apposition of the snorkel stent(s) and main aortic body is a common area of focus in preparing for these procedures. We selected our threshold sealing length based on the fact that most devices with suprarenal fixation have decreased the traditional minimum infrarenal neck length from 15-mm to10-mm, although the minimum length of the gutter required to achieve adequate proximal seal and promote thrombosis of associated gutters remains unknown. The theoretical advantage of longer sealing zone, however, has not been corroborated in vivo and comes at the expense of increased risk for snorkel stent thrombosis. Patients in our series with early type Ia endoleaks paradoxically trended toward a longer mean new neck length. In addition, the question of optimal oversizing remains unknown. In vitro data has shown that increased oversizing does yield reduction in gutter areas but also generates significantly more infolding of the main endograft with extreme (>30%) oversizing.[12]

We were unable to confirm several of our other procedural biases. It is our preference, for instance, to use main body endografts with suprarenal fixation in order to augment conformability of the parallel grafts by “pinning” the snorkel grafts against the aortic wall. The infrequent use of infrarenal devices in our series, however, limits any comparisons in this regard. A similar preference for suprarenal fixation was noted in the PERICLES registry,[7] whereby superb clinical outcomes were achieved, including a 2.9% type Ia endoleak on completion angiography, using the Zenith (Cook Medical) or Endurant (Medtronic) devices in nearly 70% of cases worldwide. In addition, we have gravitated toward preferential use of the balloon-expandable covered stents owing to their increased procedural efficiency, better visibility, and improved radial strength. Multiple reports, including ours, have noted a trend toward fewer type Ia endoleaks using balloon-expandable compared to self-expanding stents (PERICLES).[7] A recent comparative analysis also demonstrated an increased tendency for type Ia endoleak with self-expanding stents, even though no difference in technical success or patency was detected.[13] These findings may be a result of selection bias, however, since self-expanding stents are typically reserved for cases involving excessive branch vessel angulation. While there is no consensus as to the optimal combination of aortic main body and snorkel stent types, the PROTAGORAS trial did recently report excellent outcomes using a standardized Sn-EVAR protocol with combined Endurant (suprarenal fixation) and balloon-expandable snorkel stents.[9]

The risk of late or persistent type Ia endoleaks mandates close radiologic surveillance as their presence may be associated with the need for often challenging secondary procedures or even delayed rupture. While late type Ia endoleaks are relatively infrequent after Sn-EVAR, these have been reported to occur in up to 7% of cases.[6,9] Repeat balloon molding and relining of the chimney grafts with or without an aortic extension cuff may be sufficient in some cases. Others have reported success with coil or glue embolization of the gutters[7,9,14] and use of Aptus Heli-FX EndoAnchors (Medtronic Cardiovascular).[15] Our early type Ia endoleak-associated reintervention rate of 3.3% is also consistent with the 0-12.5% rate cited in the literature.[2,5–8]

The majority of patients (91.7%) in our cohort achieved aneurysm sac stabilization or regression following Sn-EVAR independent of whether an early type Ia endoleak was detected. Even in the presence of a higher incidence of early type Ia endoleak, these findings compare favorably to the >85% rate of aneurysm sac stabilization or regression noted by others.[6,8,14,16] The lack of evident causal relationship between type Ia endoleak and subsequent aneurysm sac growth may be secondary to a preponderance of low-flow proximal endoleaks, perhaps with similar flow dynamics as in type II endoleaks, or because the majority of them spontaneously resolve prior to inducing any net change on the aneurysm sac.

CONCLUSION

Gutter-related type Ia endoleak represents a relatively frequent early occurrence after ch-EVAR but appears to resolve spontaneously in the majority of cases during early to mid-term follow-up. Given that few patients require intervention related to gutter endoleaks and the presence of such endoleak does not correlate to increased risk for aneurysm sac growth, the natural history of early gutter endoleaks may be more benign than originally expected. Longer-term follow-up is required to better characterize the risk of delayed type Ia endoleak and prevent late aneurysm-related complications, as well as to further clarify the role of elective ch-EVAR in the era of branched and fenestrated technology.

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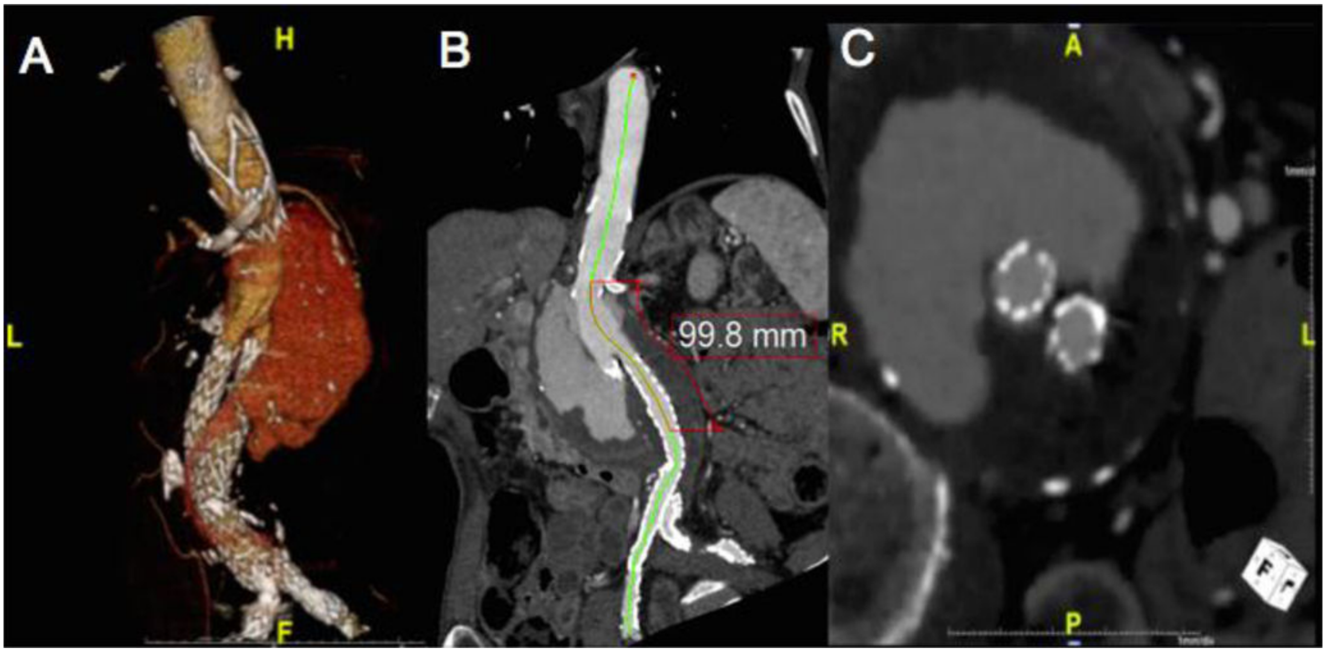


Figure 1.

Example of “long” gutter-related type Ia endoleak following EVAR with left renal snorkel stent. A three-dimensional reconstruction (A), sagittal view (B), and representative axial view (C) demonstrate extra-stent contrast extending greater than 10-mm below the snorkel stent and with caudal extension into the aneurysm sac.

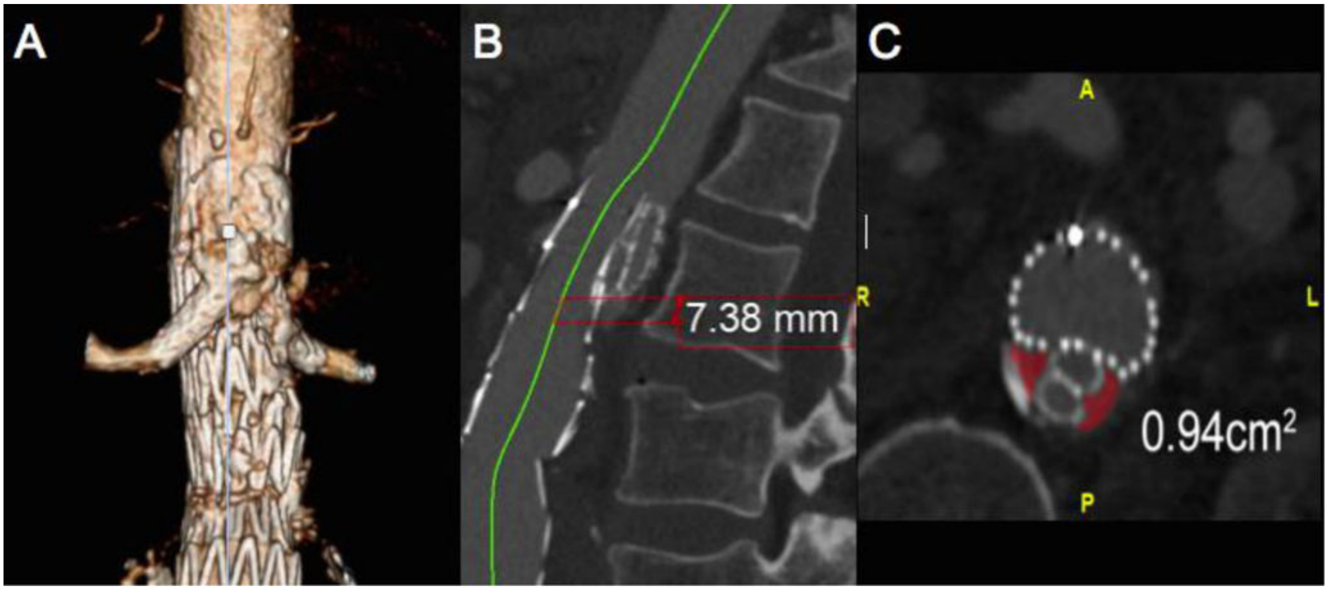
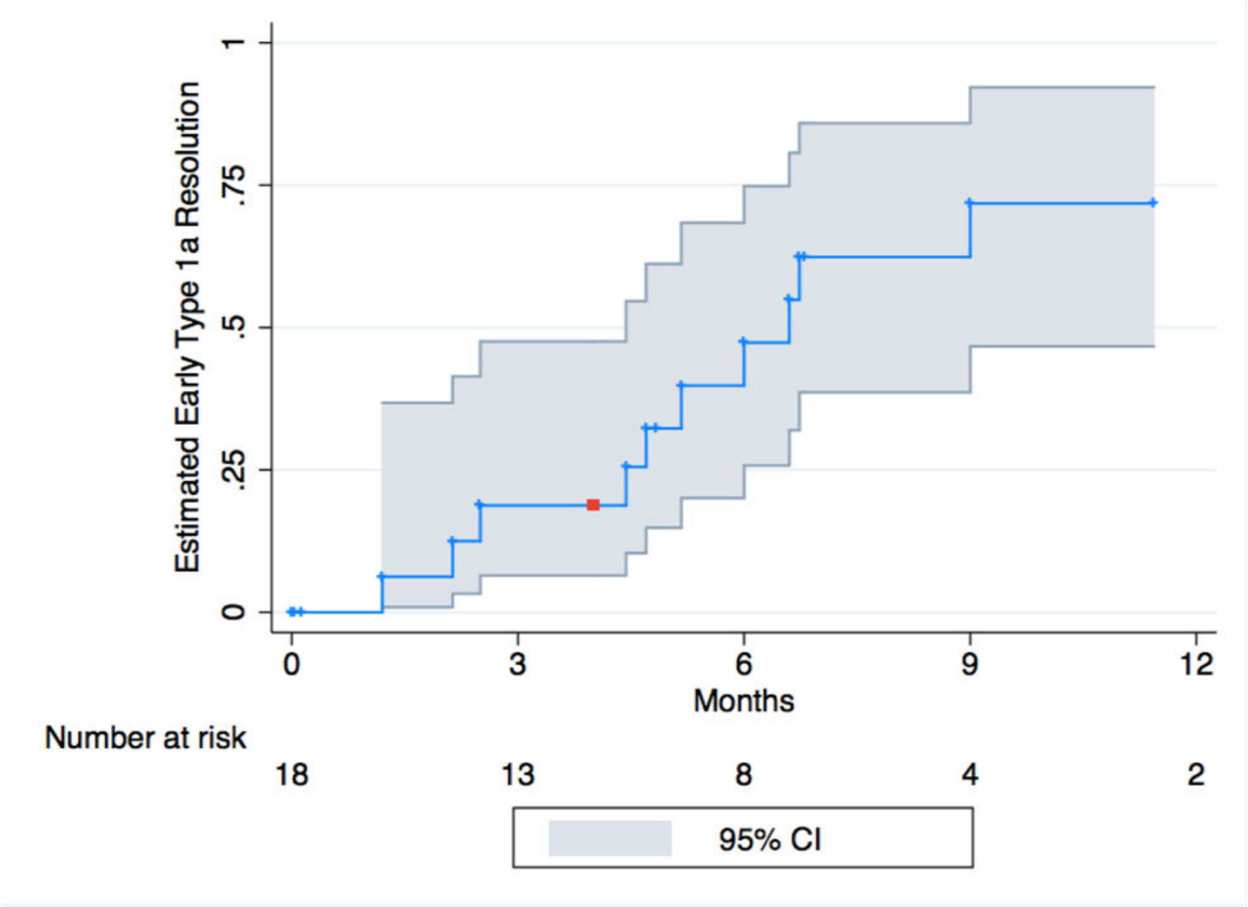


Figure 2.

Example of “short” gutter-related type Ia endoleak following EVAR with bilateral renal snorkel stents. A three-dimensional reconstruction (A), sagittal view (B), and representative axial view (C) demonstrate extra-stent contrast extending less than 10-mm below the most caudal snorkel stent but does not enter the aneurysm sac.

(A)


Estimated Early Type 1a Resolution
0
.25
.5
.75
1
0
3
6
9
12
Months
Number at risk
18
13
8
4
2
95% CI

(B)

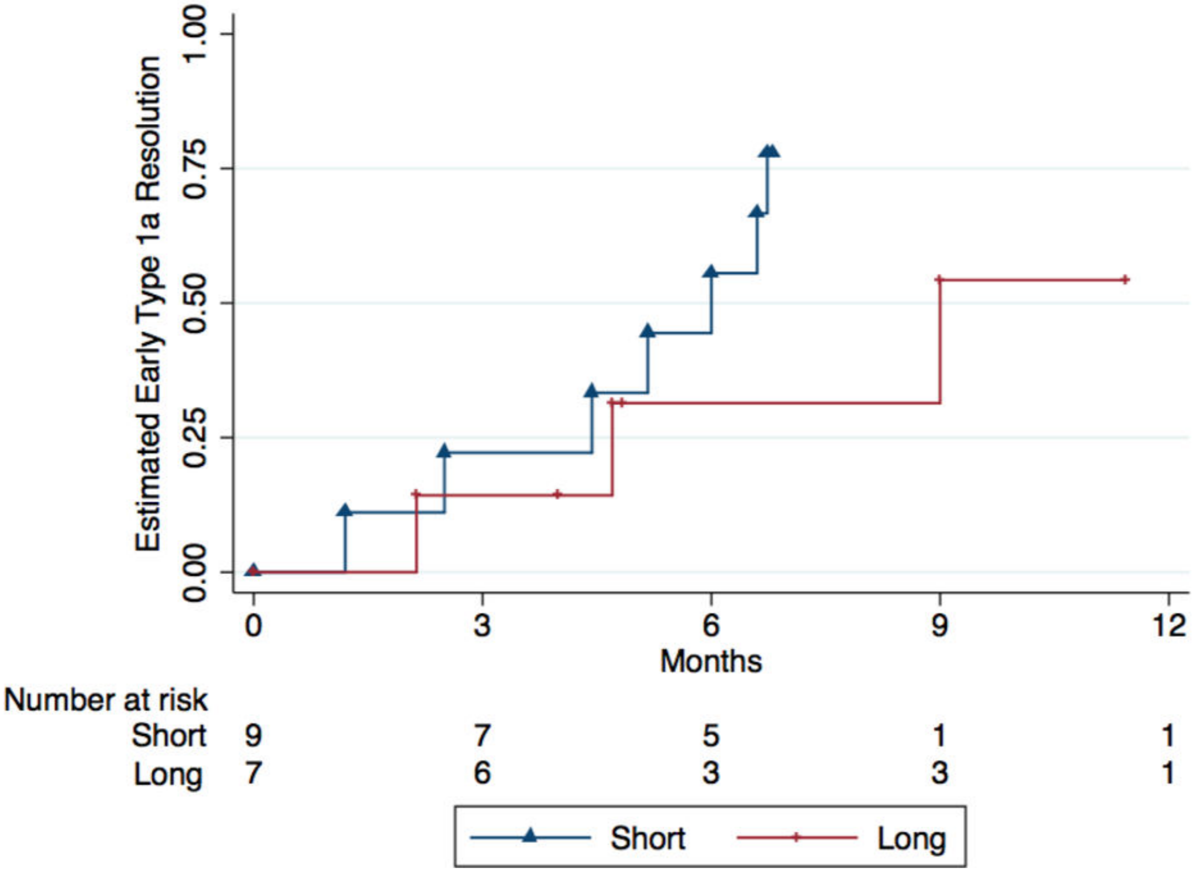


Figure 3. Spontaneous resolution of early (<30 day) type Ia gutter endoleaks following ch-EVAR

Red square indicates solitary patient who required early type Ia endoleak-associated secondary intervention (performed at four months post-procedure).

Log-rank, P=.30.

Table I

Patient demographics and comorbidities

Variable	**All patients (n=60)**	**Early type Ia endoleak**		**P**[a]
		No (n=42)	**Yes (n=18)**	
Age, years	75.8 ± 7.6	75.6 ± 7.4	76.3 ± 8.2	.72
Gender, male	42 (70.0)	28 (66.7)	14 (77.8)	.39
Comorbidities				
Coronary artery disease	42 (70.0)	30 (71.4)	12 (66.7)	.71
Congestive heart failure	17 (28.3)	10 (23.8)	7 (38.9)	.23
Hypertension	55 (91.7)	38 (90.5)	17 (94.4)	.61
Diabetes mellitus	10 (16.7)	7 (16.7)	3 (16.7)	>.99
Chronic renal insufficiency[b]	10 (16.7)	9 (21.4)	1 (5.6)	.13
Chronic obstructive pulmonary disease	21 (35.0)	15 (35.7)	6 (33.3)	.86
Hyperlipidemia	55 (91.7)	39 (92.9)	16 (88.9)	.61
Tobacco use	54 (90.0)	38 (90.5)	16 (88.9)	.85
Current smoker	21 (35.0)	15 (35.7)	6 (33.3)	.86
Prior smoker	33 (55.0)	23 (54.8)	10 (55.6)	.95
Baseline anticoagulation use	9 (15.0)	6 (14.3)	3 (16.7)	.81
Acuity				.33
Elective	53 (88.3)	36 (85.7)	17 (94.4)	
Urgent/emergent	7 (11.7)	6 (14.3)	1 (5.6)	

[a] Comparison between groups with and without presence of early type IA gutter endoleak on initial postoperative imaging.

[b] Defined as serum creatinine ≥1.5 mg/dL

Continuous variables are presented as mean ± standard deviation and categorical variables are presented as number (%).

Table II

Anatomic and procedural data

Variable	**All patients (n=60)**	**Early type Ia endoleak**		**P[a]**
		No (n=42)	**Yes (n=18)**	
Preoperative radiologic data				
Aneurysm type				.17
Juxtarenal	44 (73.3)	33 (78.6)	11 (61.1)	
Suprarenal	15 (25.0)	9 (21.4)	6 (33.3)	
Type IV TAAA	1 (1.7)	0 (0)	1 (5.6)	
Infrarenal neck diameter, mm	30.7 ± 7.8	29.7 ± 7.1	33.0 ± 9.1	.14
Infrarenal neck length, mm	2.0 ± 2.5	2.2 ± 2.5	1.6 ± 2.3	.36
Proximal (suprarenal) seal zone diameter, mm	25.1 ± 3.3	24.6 ± 3.1	26.3 ± 3.3	.06
Angulation, degrees				
Suprarenal	25.1 ± 20.5	25.0 ± 18.9	25.2 ± 24.6	.97
Infrarenal	33.8 ± 22.3	32.3 ± 21.0	36.8 ± 25.2	.54
Calcification[b], %				.50
<25	37 (88.1)	24 (85.7)	13 (92.9)	
25-50%	5 (11.9)	4 (14.3)	1 (7.1)	
Thrombus[b], %				>.99
<25	39 (92.9)	26 (92.9)	13 (92.9)	
25-50	3 (7.1)	2 (7.1)	1 (7.1)	
Procedural data				
% oversizing of main body	25.0 ± 6.6	25.7 ± 6.1	23.4 ± 7.6	.23
New neck length, mm	22.1 ± 7.6	21.5 ± 7.5	23.4 ± 8.0	.38
Main body graft				
Cuff	8 (13.3)	4 (9.5)	4 (22.2)	.18
Bifurcated device	48 (80.0)	35 (83.3)	13 (72.2)	.32
Aortouni-iliac	2 (3.3)	2 (4.8)	0 (0)	.35
Thoracic tube graft	2 (3.3)	1 (2.4)	1 (5.6)	.53

Variable	All patients (n=60)	Early type Ia endoleak		P[a]
		No (n=42)	Yes (n=18)	
Suprarenal fixation	56 (93.3)	39 (92.9)	17 (94.4)	.82
Snorkel configuration				.05
Single snorkel	13 (21.7)	6 (14.3)	7 (38.9)	
Double snorkel	44 (73.3)	34 (81.0)	10 (55.6)	
Triple snorkel	2 (3.3)	2 (4.8)	0 (0)	
Quadruple snorkel	1 (1.7)	0 (0)	1 (5.6)	
No. snorkel stents per patient	1.9 ± 0.6	1.9 ± 0.4	1.7 ± 0.8	.24
Target snorkel stents[c]				.05
Celiac artery	2 (1.8)	0 (0)	2 (6.5)	
Superior mesenteric artery	12 (10.8)	10 (12.5)	2 (6.5)	
Renal artery	97 (87.4)	70 (87.5)	27 (87.1)	
Right	53 (47.7)	39 (48.8)	14 (45.2)	
Left	44 (39.6)	31 (38.8)	13 (41.9)	
Self-expandable bare metal stent only	1 (0.9)	0 (0)	1 (3.2)	.11
Balloon-expandable covered stent	71 (64.0)	53 (66.3)	18 (58.1)	.42
Self-expandable covered stent	39 (35.1)	27 (33.8)	12 (38.7)	.62
Reinforced with bare metal stent	26 (23.4)	18 (30.0)	8 (25.8)	.71
Combined fenestrated + snorkel EVAR	12 (20.0)	6 (14.3)	6 (33.3)	.09
Fluoroscopy time, min	79.9 ± 46.6	77.5 ± 49.7	85.3 ± 39.1	.56
Contrast dose, mL	156.7 ± 64.3	158.8 ± 52.9	151.6 ± 87.0	.69

TAAA, thoracoabdominal aortic aneurysm.

[a] Comparison between groups with and without presence of early type IA gutter endoleak on initial postoperative imaging.

[b] Calculated based on 42 patients with available preoperative cross-sectional imaging.

[c] Calculated with number of target vessels/snorkel stents as denominator in each column.

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Table III

Aneurysm sac regression

Variable	**All patients (N=60)**	**Early type Ia endoleak**		**P**[a]
		No (n=42)	**Yes (n=18)**	
Maximum aneurysm sac size, mm				
Preoperative	68.0 ± 14.4	67.9 ± 15.1	68.0 ± 13.2	.99
Latest follow-up	62.7 ± 18.4	63.0 ± 18.9	61.9 ± 17.5	.83
Net change in size	−5.3 ± 11.0[b]	−4.9 ± 11.5[b]	−6.1 ± 10.0[b]	.70
Aneurysm sac regression/stabilization[c]	55 (91.7)	40 (95.2)	15 (83.3)	.13

[a] Comparison *between* groups with and without presence of early type Ia gutter endoleak on initial postoperative imaging.

[b] Represents statistically significant (P<.05) difference in aneurysm sac size between preoperative and follow-up measurements *within* each group using paired group analysis.

[c] Defined as aneurysm sac growth <5 mm on postoperative surveillance imaging.

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Table IV

Clinical outcomes

	Early Gutter-Related Type Ia endoleak			P[a]
	All (n=16)	**Short (n=9)**	**Long (n=7)[b]**	
Gutter endoleak-related re-intervention	2 (13)[c]	0 (0)	2 (29)[c]	.09
Aneurysm sac regression/stabilization	13 (81)	8 (89)	5 (71)	.37
Aneurysm-related mortality	0 (0)	(0)	(0)	>.99

[a] Comparison between groups with short vs. long gutter-related type Ia endoleak on initial postoperative imaging.

[b] Excludes 2 patients without imaging >1 month post-procedure.

[c] Included 1 patient awaiting re-intervention.