Fate of Aneurysmal Common Iliac Artery Landing Zones Used for Endovascular Aneurysm Repair

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Claire L. Griffin, MD¹, Salvatore T. Scali, MD², Robert J. Feezor, MD², Catherine K. Chang, MD², Kristina A. Giles, MD², Javairiah Fatima, MD², Thomas S. Huber, MD, PhD², and Adam W. Beck, MD²

Abstract

Purpose: To determine outcomes of aneurysmal common iliac arteries (aCIA) used for landing zones (LZs) during endovascular aneurysm repair (EVAR). **Methods:** This single-center study retrospectively compared 57 EVAR patients (mean age 72±8 years; 56 men) with 70 aCIAs (diameter ≥20 mm) to 25 control EVAR subjects (mean age 73±7 years; 20 men) with 50 normal (≤15-mm) CIA LZs treated consecutively during the same time interval. The CIA LZ measurements were analyzed using random effects linear mixed models to determine diameter change over time. Life tables were used to estimate freedom from endoleak, reintervention, and all-cause mortality. **Results:** The mean maximum preoperative CIA diameter in the aCIA LZ group was 24.8±4.5 mm (range 20.0–47.3, median 23.9) vs 13.6±1.5 mm (range 9.2–15.0, median 13.9; $p<0.001$) in the controls. Nineteen aCIA LZs were treated outside the instructions for use of the device. Median follow-up in the aCIAs LZ cohort was 39.2 months [interquartile range (IQR) 15, 61] vs 49.3 months (IQR 36, 61) in the controls ($p=0.06$). The rate of aCIA LZ change (0.09 mm/mo, 95% CI 0.07 to 0.1) was significantly greater than controls (0.03 mm/mo, 95% CI –0.009 to 0.07; $p<0.0001$). No type Ib endoleaks developed in either group; however, aCIA LZ patients had 6 (11%) iliac limb-related reinterventions. There were significantly more endograft-related reinterventions in the aCIA LZ patients ($n=10$, 14%) compared with controls ($n=2$, 4%; $p=0.06$). There was no difference in mortality or freedom from any post-hospital discharge endoleak. **Conclusion:** Aneurysmal CIA LZs used during EVAR experience greater dilatation compared with normal LZs, but no significant difference in outcome was noted in midterm follow-up. However, an increased incidence of graft limb complications or endograft-related reintervention may be encountered. Use of aCIA LZs appears to be safe; however, greater patient numbers and longer follow-up are needed to understand the clinical implications of morphologic changes in these vessels when used during EVAR.

Keywords

abdominal aortic aneurysm, dilatation, endoleak, endovascular aneurysm repair, iliac artery, landing zone, reintervention, remodeling, stent-graft

Introduction

Currently, endovascular aortic repair (EVAR) is performed in up to 70% of patients with an abdominal aortic aneurysm.^{1,2} Concurrent iliac aneurysm with an abdominal aortic aneurysm (AAA) is present in 15% to 44% of subjects and can occur in isolation in 2% of patients.^{3–6} The definition of an iliac artery aneurysm is typically described by a vessel diameter 1.5 times the normal adjacent reference vessel diameter.⁷ Alternatively, reporting standards have suggested an absolute diameter ≥18 mm in men (≥15 mm for women) for classification of common iliac artery (CIA) aneurysm.⁷ Intervention is usually recommended for diameters between 30 and 40 mm^{8–10} when an isolated CIA aneurysm is present. Traditionally, iliac diameters ≥18 to 20 mm are repaired

¹Dartmouth Hitchcock Medical Center, Lebanon, NH, USA

²Division of Vascular Surgery and Endovascular Therapy, University of Florida, Gainesville, FL, USA

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Claire L. Griffin and Salvatore T. Scali contributed equally to this work and have shared first authorship.

Corresponding Author:

Salvatore T. Scali, Division of Vascular Surgery and Endovascular Therapy, University of Florida College of Medicine, Suite NG-45, 1600 SW Archer Road, Gainesville, FL 32610 USA.
Email: salvatore.scali@surgery.ufl.edu

Figure 1. A diagram of patient flow through the inclusion and exclusion process.

when open infrarenal AAA repair is completed in patients with good life expectancy.¹¹ During EVAR, CIA vessel diameters >20 mm can be treated in a number of ways, but most are managed with internal iliac artery (IIA) embolization and limb extension into the external iliac artery.¹²

Unfortunately, pelvic ischemic complication rates after IIA coverage can range from 13% to 55%,^{12–14} causing surgeons to frequently attempt internal iliac preservation. To salvage the hypogastric artery in some patients, device manufacturers offer EVAR iliac limbs that are approved for deployment in vessels up to 25 mm in diameter, which constitutes using an aneurysmal vessel as a landing zone (LZ). Furthermore, off-label techniques for landing in large iliac arteries are often reported, such as inverted aortouni-iliac devices and “bell-bottom” techniques using aortic cuffs.^{15–17}

Limited and conflicting results exist with regard to the natural history and outcomes of using aneurysmal CIA (aCIA) LZs during EVAR. Some series have demonstrated good short and midterm outcomes, while larger registry data suggest that the presence of an iliac aneurysm can lead to a higher risk of type Ib leak, limb occlusion, secondary intervention, or aneurysm rupture after EVAR.^{3,18} The purpose of this study was to examine the natural history of aCIAs that are used as landing sites for aortic stent-grafts.

Methods

Study Design and Cohort

A prospectively maintained database was queried to identify patients who underwent elective EVAR between January 2002 and February 2011 and had at least one aCIA utilized as a distal LZ. An aCIA was defined by an adventitia to adventitia diameter ≥ 20 mm on axial computed tomography (CT). Of the 799 EVARs performed during the time period, 279 patients fit the selection criterion. For the purpose of this investigation, each vessel was considered individually, yielding 389 aCIAs that were further reviewed.

Subsequently, vessels were excluded from the study if the aCIA was not used as the LZ for the endovascular repair (ie, the aneurysmal segment was proximal or distal to the actual LZ of the stent). Additionally, patients undergoing IIA embolization with external iliac limb extension were intentionally excluded. Similarly, subjects who underwent bypass, fenestration, or sandwich/chimney techniques to preserve the IIA were not analyzed. After these exclusions, 132 aCIA LZs remained; of these, 70 vessels in 57 patients (mean age 72 ± 8 years; 56 men) had at least 2 postoperative CT scans available for time-dependent analysis (Figure 1), so they were entered into the study.

Table 1. Patient Demographics and Comorbidities.

Characteristic	Aneurysmal Iliac LZ ^a (n=57)	Normal Iliac LZ ^a (n=25)	P
Age, y	72±8	73±7	0.4
Men	56 (98)	20 (80)	0.01
Body mass index, mg/kg ²	29.3±4.1	27.2±5.6	0.1
Comorbidities			
Hypertension	48 (84)	19 (76)	0.4
Coronary artery disease	36 (63)	13 (52)	0.5
Dyslipidemia	39 (68)	15 (60)	0.5
COPD	19 (33)	8 (32)	1
Cerebrovascular disease	11 (19)	7 (28)	0.4
Peripheral artery disease	12 (21)	1 (4)	0.1
Arrhythmia	5 (9)	4 (16)	0.4
Chronic renal insufficiency	5 (9)	1 (4)	0.7

Abbreviations: COPD, chronic obstructive pulmonary disease; LZ, landing zone.

^aContinuous data are presented as the means ± standard deviation; categorical data are given as the counts (percentage).

For comparative analysis, a control group of 25 consecutive patients (mean age 73±7 years; 20 men) treated during the same time period with at least 24 months of CT follow-up and 50 normal caliber (≤15 mm) CIA LZs used during EVAR were identified from the database. No patient in either cohort received renal/visceral chimney and/or fenestration repair. The demographics and comorbidities of the groups are presented in Table 1.

This study was approved by the institutional review board for the study of human subjects (IRB#562-2011). The need for patient consent was waived since there was no direct contact or harm that occurred as a result of the analysis.

Anatomical Measurements

Measurements were obtained from the preoperative CT arteriogram (CTA) at 7 predefined locations: the major and minor axes of the AAA at the point of maximal dilation; the most distal diameter of the CIA of interest; the largest diameter of the CIA of interest; and 3 additional diameters spaced 10 mm apart beginning at the iliac bifurcation and moving proximally toward the aortic bifurcation. All diameter measurements were performed from adventitia to adventitia using the minor axis of the vessel in an orthogonal plane based on the impression of the axis of flow within the iliac artery.

The postoperative CT scans were evaluated in a similar manner, with the LZ defined by the distal-most extent of the stent (Figure 2). The measurements obtained included the largest diameter of the vessel of interest and 2 measurements of the vessel diameter ~10 mm apart beginning at the distal end of the stent using the first slice that included 360° visualization of metal. Two measurements were obtained at

10-mm increments proximal to the distal end of the stent. All measurements were obtained using Phillips iSite software (Philips Medical Systems, Inc, Shelton, CT, USA) at 300% magnification. Vessel measurements were recorded to the nearest tenth of a millimeter by two independent observers (C.G. and S.S.). There was excellent agreement between the two independent reviewers across all measured variables (mean difference in measurements 0.02±0.67, Spearman correlation 0.99, p=0.65).

EVAR Procedure

During the study interval, no standardized algorithm existed to govern selection of an aCIA LZ for use during EVAR. Patients typically underwent preoperative thin-cut (≤2 mm) CT angiography (CTA) with centerline reconstruction (TeraRecon, Foster City, CA, USA) for graft selection and sizing. In general, the iliac stent-graft oversizing goal was 5% to 15% greater than the outer diameter of the iliac artery LZ; however, due to the presence of aneurysmal vessels, thrombus, and/or device limitations, this could not be achieved in all cases. Surgeon discretion determined usability of aCIA LZs, and no device-specific algorithm was employed during the study interval to address thrombus, calcification, and/or vessel tortuosity.

Endovascular aneurysm repair was performed in a hybrid operating room with a ceiling-mounted imaging system. If a bell-bottom¹⁹ or flared stent-graft limb technique was employed, patients received either a flared limb from the manufacturer of the main body stent-graft, an aortic extension cuff, or an aortouni-iliac conversion device using methods previously described.^{17,19,20} All overlapping graft segments were molded with a compliant balloon, and completion digital subtraction angiography was obtained to

Figure 2. Common iliac artery measurements were obtained on cross-section imaging at 7 predefined locations: (A) 2 measurements were obtained at the distal end of the stent at the first site of where a 360° visualization of metal was noted. (B) The transverse short axis measurement of the distal end of the stent was completed on 300% image magnification with attempts to ensure this was done on orthogonal views. Illustrations of the additional cross-sectional measurements that were obtained on (C) preoperative and (D) postoperative computed tomography arteriograms.

detect any endoleak and verify the status of the branch vessel anatomy. The stent-grafts implanted were Zenith (Cook Medical, Bloomington, IN, USA), Excluder (W.L. Gore & Associates, Inc, Flagstaff, AZ, USA), and AneuRx/Talent (Medtronic, Inc, Minneapolis, MN, USA).

Postoperative CT surveillance with arterial and delayed-phase venous imaging was typically obtained at 1, 6, and 12 months and annually thereafter unless radiographic findings dictated otherwise. Timing and need for any reintervention was based on the attending surgeon's judgment.

Outcome Measures and Statistical Analysis

The primary outcome measures were the iliac LZ diameter change over time and reintervention-free survival. Secondary outcomes included 30-day morbidity/mortality, freedom from endoleak, and all-cause mortality. Patient comorbidities, EVAR adjuncts, complications, outcomes,

and reintervention were defined according to the Society for Vascular Surgery reporting standards.²¹ Nominal stent diameters and procedure-specific details were obtained from implantation records. Vessels treated with a device outside the instructions for use (IFU) were independently analyzed.

The average rate of vessel dilation (mm/mo) was calculated by dividing the difference between the most recent CIA LZ diameter and the preoperative CIA LZ diameter by the follow-up duration in months. The rates are given as the group mean in mm/mo with 95% confidence interval (CI).

Random effects linear modeling was utilized to compare outcomes across time between the aneurysmal and normal iliac LZ groups. To compensate for repeated observations on the same patient, mixed models were used. To account for the clustering of observations on patients, a random intercept was modeled, and when it improved the model fit,

Table 2. Procedure Characteristics and Postoperative Outcomes.

	Aneurysmal Iliac LZ ^a (n=57, 70 vessels)	Normal Iliac LZ ^a (n=25, 50 vessels)	p
Preoperative AAA diameter, mm	56.9±12.9	58.3±12.2	0.5
Main device type			
Zenith	58 (83)	36 (72)	
Excluder	8 (11)	8 (16)	
AneuRx/Talent	4 (6)	6 (12)	0.3
Off-label iliac LZ device use	19 (27)	0	0.01
Aortic cuff	16	—	
Reversed aortic converter	3	—	
Operative variables			
Contrast volume, mL	97±32	95±42	0.3
Fluoroscopy time, min	29±14	27±21	0.1
Procedure time, min	126±47	112±64	0.05
Estimated blood loss, mL	250 [200, 250]	200 [150, 250]	0.01
Intraoperative complication	3 (5)	3 (12)	0.4
Adjunct procedures	19 (33)	1 (4)	0.004
Embolization or IIA bypass (contralateral iliac)	10 (18)	0	
Iliac/femoral access procedure	6 (11)	1 (4)	
Aortic/visceral stent	3 (5)	0	0.004
Postoperative outcomes			
LOS, d	1 [1, 26]	1 [1, 7]	0.9
30-Day mortality	0	0	—
Postoperative complication ^b	10 (18)	4 (16)	0.8
Neurologic ^c	5	1	
Cardiac	0	0	
Pulmonary	0	0	
Gastrointestinal	0	0	
Renal	1	1	
Bleeding	1	1	
Ischemic	3	1	

Abbreviations: AAA, abdominal aortic aneurysm; IIA, internal iliac artery; LOS, length of stay; LZ, landing zone.

^aContinuous data are presented as the means ± standard deviation or median [interquartile range]; categorical data are given as the counts (percentage).

^bAny postoperative complication that occurred within 12 months of the index operation defined according to the Society for Vascular Surgery reporting standards for endovascular aneurysm repair (EVAR) care.²¹

^cNeurologic complications were all spinal headaches in patients treated with an epidural blood patch; renal complications were doubling of creatinine level and/or 50% decline in estimated glomerular filtration rate while in-hospital or within 30 days; ischemic complications included distal embolization, limb occlusion, access vessel stenosis, or pelvic ischemia (eg, buttock claudication).

a random slope for each patient was generated. Because thrombus can have significant impact on LZs, 3 patients with >50% circumferential thrombus of the aneurysmal iliac LZ were not included in the outcome modeling.

Kaplan-Meier analysis was used to estimate long-term outcomes with variable follow-up including freedom from endoleak, incidence of reintervention, and survival; groups were compared with the long-rank test. Survival estimates are presented with ± the standard error. All deaths were verified by query of the Social Security Death Index Masterfile. The statistical analysis was performed using the R statistical software package (version 3.0.2; R Foundation for Statistical

Computing, Vienna, Austria; <http://www.r-project.org>). The threshold of statistical significance was $p < 0.05$. Continuous data are presented as the means ± standard deviation or median and interquartile range (IQR); categorical data are given as the counts (percentage).

Results

There were no significant differences in demographics, comorbidities (Table 1), or distribution of main body endografts (Table 2) between the study group and controls. Operative characteristics (Table 2) were notably different

Figure 3. (A) The difference in remodeling behavior after endovascular repair between aneurysmal (≥ 20 mm) and normal (≤ 15 mm) iliac arteries utilized for distal iliac stent-graft landing zones. The most rapid rate of iliac artery landing zone dilation occurs within the first 6 months after implantation, and aneurysmal common iliac artery landing zones dilate at a greater rate compared with control vessels. (B) Regardless of whether or not an aneurysmal iliac landing zone was used during endovascular repair, similar rates of sac regression were observed.

between groups, with the aCIA LZ patients having significantly greater blood loss ($p=0.01$) and longer procedures (time from initial incision and/or skin puncture to dressing application). There were significantly more intraoperative adjunctive procedures used for the aCIA LZ cases; however, postoperative morbidity and length of stay were not different.

Iliac Landing Zone Changes

The mean maximum preoperative CIA diameter (not the LZ site) was 24.8 ± 4.5 mm (range 20.0–47.3, median 23.9), with a mean preoperative iliac bifurcation diameter of 21.8 ± 2.8 mm. By design, control patients had significantly smaller maximum preoperative CIA LZ diameters: 13.6 ± 1.5 mm (range 9.2–15.0, median 13.9; $p<0.001$).

Iliac LZ behavior over time between the 2 groups is displayed in Figure 3A. The rate of aCIA LZ change was significantly greater (0.09 mm/mo, 95% CI 0.07 to 0.1) than in the control patients (0.03 mm/mo, 95% CI –0.009 to 0.07; $p<0.0001$). The most rapid growth of the iliac LZ was seen in the first 6 months after EVAR for both groups, and this rate decreased over time to ultimately conform to nominal stent diameter (Supplemental Figure 1, available at <http://jet.sagepub.com/content/by/supplemental-data>). This difference in iliac LZ behavior did not correspond to any difference in rates of maximal AAA sac diameter

regression (-0.5 mm/mo, 95% CI -0.6 to -0.4 ; $p=0.8$; Figure 3B).

Stent Oversizing and Iliac LZ Behavior

The iliac stent-grafts used for the aCIA LZ patients were <23 mm in 8 vessels, while the remaining 62 vessels were treated with 23- to 32-mm devices. Nineteen aCIA LZs were treated outside the IFU using a bell-bottom technique with aortic cuffs ($n=16$; diameter range 28–32 mm) or reversed aortouni-iliac converter devices ($n=3$). The mean device diameter was 24.6 mm (range 20–32), which resulted in an average oversizing of $11.3\% \pm 10\%$ (range –16% to 31%) vs $5.6\% \pm 14.6\%$ (range 0%–28%) in the controls ($p<0.001$).

At the 12-month time point, 107 (89.2%) of the 120 iliac LZ vessels with available follow-up experienced dilatation. More specifically, this increased to 100% of the 70 aCIA LZ vessels for all remaining time points. In the control cohort, the mean preoperative CIA LZ diameter measured 12.6 ± 1.5 mm and mean device diameter was 14.5 ± 2.2 mm. Similar to the aCIA group, a majority of LZs experienced dilatation over time but this did not become apparent until later in follow-up (78.1% by 36 months; $p=0.02$ for difference in rates compared with aCIA group).

There was a significant correlation between LZ dilatation and percentage of stent oversizing for aCIA LZ

Figure 4. (A) Iliac stent-graft oversizing has a much greater impact on an aneurysmal iliac landing zone compared with control vessels. (B) There is no difference in the overall rate of change between on-label and off-label groups for treatment of aneurysmal iliac landing zones; however, both methods result in a greater rate of change compared with control vessels managed within the instructions for use.

Table 3. Outcomes After Hospital Discharge for Patients Undergoing Endovascular Aneurysm Repair With or Without Aneurysmal Common Iliac Artery Landing Zones (LZ).^a

Variable	Aneurysmal Iliac LZ ^b (n=57)	Normal Iliac LZ ^b (n=25)	p
Any death after 30 days	12 (24)	6 (24)	0.8
Any operative reintervention	9 (18)	2 (8)	0.3
Endograft reintervention	7 (12)	0	0.1
Any endoleak	17 (24)	10 (20)	0.7
None	53 (76)	40 (80)	
Type Ia	1 (1)	0	
Type Ia/II	1 (1)	0	
Type Ib	0	0	
Type II only	15 (21)	10 (20)	
Type III	0	0	0.9

^aMedian follow-up was 39.2 months (IQR 15, 61) for the aneurysmal iliac LZ patients and 49.3 months (IQR 36, 61) for control patients.

^bData are given as the counts (percentage).

subjects but not controls (Figure 4A). In the aCIA LZ group, the estimated slope of the change in LZ diameter by month was 0.20 mm steeper than in the control group (95% CI 0.073 to 0.330; $p=0.002$). The greatest rate of change occurred in the first 6 months after implantation. However, at 12 months, the mean rate of aCIA LZ diameter change was 1.8 ± 1.5 mm/y (95% CI 1.3 to 2.3) compared with 1.1 ± 2.0 mm/y (95% CI -0.3 to 2.5) in control subjects ($p=0.46$). Notably, on- and off-label iliac LZ management (Figure 4B) had significant differential impact on LZ dilatation

rate over time compared with controls [0.13 mm/mo ($p<0.001$) vs 0.05 mm/mo ($p=0.006$), respectively].

Outcomes

Median follow-up was 39.2 months (IQR 15, 61) for the aCIA LZ group vs 49.3 months (IQR 36, 61) for the control patients ($p=0.06$). Data on deaths, reinterventions, and endoleak detected after hospital discharge are shown in Table 3. Despite virtually all iliac LZs experiencing dilatation over time, no

type Ib endoleak was observed in either cohort. The corresponding 3- and 5-year freedom from endoleak rates were not different: $74\% \pm 5\%$ and $74\% \pm 5\%$, respectively, for the aCIA LZ vs $84\% \pm 5\%$ and $76\% \pm 7\%$, respectively, for controls ($p=0.42$; Figure 5A). There was a trend toward a higher rate of endograft-related secondary intervention for the aCIA LZ patients (8, 14%) compared with none in the control group; however, this was not significant ($p=0.06$).

The details of the various reinterventions in the 2 groups are outlined in Table 4. No difference in pattern or frequency of failure for on- or off-label device use was noted. Six (11%) patients in the aCIA LZ group underwent reintervention for an iliac limb-related problem. Notably, 2 open conversions and an endoconversion to an aortouni-iliac repair occurred in the aCIA LZ patients compared with none in the control group. The 2 open conversions were due to a persistent type Ia endoleak after attempted aortic cuff redilation and for acute aortic occlusion due to limb thrombosis. The endoconversion occurred as a result of aortic neck endograft migration. No deaths were attributable to AAA or CIA complications, reintervention, or rupture in either group during the study interval.

Notwithstanding these events, the reintervention-free survival (for any indication) at 3 and 5 years was not significantly different: $84\% \pm 5\%$ and $81\% \pm 6\%$, respectively, for the aCIA LZ vs $91\% \pm 4\%$ and $91\% \pm 4\%$, respectively, for controls ($p=0.13$; Figure 5B). During the follow-up interval, 12 (24%) aCIA LZ patients died compared with 6 (24%) control patients ($p=0.8$). The corresponding estimated 3- and 5-year survival rates were $84\% \pm 5\%$ and $84\% \pm 5\%$, respectively, for the aCIA LZ vs $92\% \pm 5\%$ and $84\% \pm 7\%$, respectively, for controls ($p=0.67$; Figure 5C).

Discussion

Consistent with the existing EVAR literature, a third of patients in our institutional experience had at least one CIA that was ≥ 20 mm in size, and some were used as a distal LZ during EVAR for IIA preservation. Overall procedure complexity is greater for patients with aneurysmal iliac LZs compared with controls. For aneurysmal and nonaneurysmal iliac LZs with sufficient CT follow-up, virtually all LZs dilated over time, and the rate and degree of dilation was greater for aCIA LZs compared with control vessels. Interestingly, stent-graft oversizing and off-label device use were associated with different rates of aCIA LZ dilatation compared with control vessels. Despite differential behavior between aCIA and control iliac LZs, no association with loss of distal seal and fixation (eg, type Ib endoleak) or higher rates of late endoleak were observed. Notably, numerically higher rates of any operative reintervention or limb complications occurred in the aCIA LZ patients during follow-up; however, overall morbidity and mortality were not significantly different compared with normal iliac LZ subjects.

Figure 5. Kaplan-Meier curves for (A) freedom from endoleak during follow-up, (B) freedom from reintervention, and (C) long-term survival. There were no differences between the groups.

Endovascular aneurysm repair has evolved and is frequently offered based primarily on anatomic considerations and the ability to achieve short-term technical success rather than necessarily being based on overall patient health.²²

Table 4. Rationale and Description of Reinterventions.

Patient	Reason for Reintervention(s)	Reintervention	Timing, mo	Outcome
Aneurysmal iliac LZ				
1	Graft limb dilation (impending loss of seal)	Right iliac limb extension	45.2	Sac regression, no endoleak
2	Type Ia endoleak	Proximal aortic cuff	13.3, 13.8	Conversion
3	Left graft limb thrombosis, type II endoleak	Right→left fem-fem bypass, IMA ligation ×2, translumbar glue embolization	8.8, 28.6, 32.9, 63.0	Sac regression, no endoleak
4	Right limb thrombosis	Left→right fem-fem bypass	16.6	Sac regression, no endoleak
5	Limb retraction	Right iliac limb extension	15.2	Sac regression, no endoleak
6 ^a	Right EIA stenosis, fall in ABI	Right EIA self-expanding stent	6.5	Sac regression, no endoleak
7 ^a	Mycotic right femoral pseudoaneurysm	Left→right fem-fem bypass	0.4	Sac regression, no endoleak
8 ^a	Left femoral pseudoaneurysm	Patch arterioplasty	0.9	Sac regression, no endoleak
9 ^a	Right limb thrombosis, acute aortic occlusion	Right→left fem-fem, aortobifemoral bypass	13.6, 45.4	Conversion
10 ^a	Proximal neck migration	Conversion to aortouni-iliac with left→right fem-fem bypass	49.9	Endoconversion
Normal iliac LZ				
1	Bilateral femoral stenosis	Bilateral femoral interposition bypass	5.7	Sac regression, no endoleak
2	Left renal stenosis, ↓eGFR	Left renal stent	35.0	Sac regression, no endoleak

Abbreviations: ABI, ankle-brachial index; EIA, external iliac artery; eGFR, estimated glomerular filtration rate; IMA, inferior mesenteric artery; LZ, landing zone.

^aOff-label device use.

Thus, younger patients with a longer life expectancy are often treated with EVAR, and the impact of aneurysm anatomy and adherence to the device's IFU criteria on repair durability has become increasingly important.²³ The variable behavior of aCIA LZs over time and the observation that some reinterventions can occur years after the index procedure underscore the need for caution and vigilant surveillance when utilizing these vessels for a LZ during EVAR.

Successful endovascular aneurysm exclusion requires two simple concepts to be met, obtaining both seal and fixation in normal tissue proximal and distal to the aneurysm. Multiple device strategies exist to accomplish proximal fixation, such as bare springs and hooks, or anatomic fixation at the aortic bifurcation. Additionally, all devices are generally oversized with relation to the proximal and distal LZ to provide outward radial force against the vessel wall, which affords additional fixation and seal. This outward force is known to cause dilation of aortic LZs over time and has been noted by many investigators using various EVAR devices.^{24–26} When determining adequacy of a distal LZ during EVAR, vessel diameter, tortuosity, and calcification are important considerations. Ideally, at least 1 to 1.5 cm of uniform diameter iliac artery with minimal calcification and thrombus are used. In our current clinical practice, we

attempt to avoid landing in thrombus and frequently extend iliac limbs to avoid landing in tortuous segments of the vessel.

Although there are many reports of aortic LZ dilation after EVAR, few studies specifically focus on the natural history of an aCIA LZ. McDonnell et al²⁷ published their series of 100 consecutive patients with large iliac arteries to determine if they increased the risk of type Ib endoleak. However, their study time period ended in 2002, before the advent of larger iliac limb devices, and therefore the mean size of the vessels evaluated was only 19.7 mm, below the cutoff of the present study. They encountered a type Ib endoleak rate of 7%. While the present study had no type Ib endoleaks, the iliac-related reintervention rate of 11% is similar to their series.²⁷

Earlier studies assessing the feasibility of the bell-bottom technique included larger caliber vessels in their cohorts, but the numbers are very small and the follow-up is short.^{6,20,28} Naughton et al¹⁹ published a series on the management of aCIA LZs using either bell-bottom or flared limb techniques compared with IIA embolization with distal external iliac artery LZ extension. These authors demonstrated that there was no significant difference in type Ib endoleak or iliac limb patency; in fact, the overall rate of complications and reintervention was lower in the

bell-bottom group. Notably, the average stent limb size in their cohort of 166 patients was 20 mm, with only 20 subjects treated with iliac limbs ≥ 24 mm. It is therefore difficult to know if the LZs themselves were aneurysmal given the inconsistency in the anatomic definitions used to define iliac aneurysm.⁷ Similarly, Kirkwood et al²⁹ examined the fate of aCIAs managed during EVAR, and vessels were specifically excluded if the distal LZs were ≥ 20 mm. They reported that patients treated with flared limbs were not routinely predisposed to future CIA growth unless they had greater stent-graft oversizing. Our results corroborate that stent-graft oversizing within an aCIA LZ can lead to greater iliac artery diameter change over time.

The finding in this study that there was correlation between iliac artery dilation and stent-graft oversizing was not surprising, particularly since virtually all iliac vessels (aCIA LZ or control) experienced some dilatation. This ubiquitous growth was also seen in the study on proximal neck dilatation over time by Monahan and colleagues.²⁴ Specifically, they noted a stronger correlation between graft oversizing and proximal LZ dilatation (Spearman coefficient $\rho=0.61$; $p<0.001$) compared with iliac LZs in the Kirkwood et al²⁹ series. This apparent difference in proximal and distal LZ behavior may relate to the varying distribution of patients with significant oversizing in the 2 studies, with the average oversizing of $29\%\pm 10\%$ in the Kirkwood et al²⁹ series vs $12.7\%\pm 10.3\%$ in the Monahan study.²⁴ Given these findings, we currently recommend only 5% to 10% (maximum) oversizing in aneurysmal iliac vessels. We do not alter our normal post-EVAR surveillance protocol unless we see a $>10\%$ change in the vessel diameter over time and/or a change in aortic aneurysm diameter. In those cases, we may opt for 6-month interval imaging and/or reintervention depending on the clinical scenario.

Limitations

The results of this study must be considered within the limitations of its single-center, retrospective design. This analysis has relatively small patient and vessel numbers, with modest follow-up, so the possibility of type II error cannot be understated. Although no significant differences in endograft-related reintervention were detected, it is important to note that patients undergoing EVAR using aCIA LZ have more complex anatomy. This is evident in the significant difference in operative complexity (Table 2), as well as a trend toward higher rates of any endograft and/or iliac limb-related reintervention. Also, our study represents predominantly one device (Zenith), and the results may not be applicable to other devices on the market (Supplemental Table 1).

This study underscores the need for long-term surveillance, especially in this subgroup of patients. Unfortunately,

the increasing number of patients lost to observation is likely related to the tertiary nature of our practice in combination with underlying patient-related socioeconomic and geographic constraints that preclude longer-term follow-up. Despite this limitation, the follow-up in this analysis is comparable to other series looking at CIA LZ behavior. In an effort to address these issues in our EVAR patients, we are creating a network with our referring providers as part of our multidisciplinary Aorta Center; this will allow more efficient image sharing and better long-term patient follow-up.

Importantly, no standardized protocol was in place over the study interval to determine which method and technique would be employed when aCIA LZs were used during EVAR. At present, our practice still does not employ a specific treatment algorithm to manage aCIAs since the constellation of the variable anatomic constructs, patient covariates, and preferences for repair are unique. Imaging artifacts may have led to imprecise vessel diameter measurements, which could influence the results; however, our interobserver variability was reasonable.

There was no determination of the degree of thrombus, calcification, or vessel tortuosity. Since these variables can have significant implications for LZ outcomes during EVAR, 3 aCIA LZ patients with significant thrombus burden were excluded from the outcome modeling. Notably, center-line analysis was not performed, so more precise orthogonal vessel measurements could have provided greater anatomical fidelity. Previous publications have demonstrated that cross-sectional CT imaging can be comparable to centerline analysis for routine EVAR planning,^{30,31} with minimal interobserver variability,³² so it is not immediately evident that this limitation would have led to a different conclusion about aCIA LZ morphologic changes with time. Nonetheless, we were rigorous in our methodology and made multiple long- and short-axis vessel measurements, which should provide ample assessment of iliac LZ anatomy for analysis.

Conclusion

This report demonstrates that in early and midterm follow-up, aneurysmal iliac arteries may provide sufficient seal and fixation to be utilized as a landing site for aortic stent-grafts. However, these aneurysmal vessels do dilate similar to aortic landing zones after EVAR, and the dilatation is greater than what is seen in normal CIA LZs. Importantly, this dilatation tends to halt once the vessel reaches the nominal stent diameter, and CIA dilatation was not significantly associated with increased risk of losing seal or fixation. However, elevated rates of limb and/or any endograft-related reintervention were noted in the aCIA patients, and longer follow-up may continue to demonstrate increasing rates of reintervention. Thus, longer term studies with greater

patient numbers are warranted to further determine the implications of aCIA LZ remodeling on EVAR outcomes.

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