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Changes in Apposition of Endograft Limbs in the Iliac Arteries After Endovascular Aneurysm Repair: Determination With New Computed Tomography–Applied Software

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Abstract

Purpose: To validate new computed tomography (CT)–applied software used to determine endograft limb position and apposition after endovascular aneurysm repair (EVAR). **Materials and Methods:** Twelve EVAR patients (mean age 81±6 years; 10 men) with distal stent-graft extensions for 15 (3 bilateral) type Ib endoleaks during follow-up were selected based on the availability of the following CT studies: pre-EVAR, 1 month, and the penultimate scan prior to the scan disclosing the type Ib endoleak. Twelve patients (mean age 82±7 years; 11 men) without endoleak and a similar interval between the primary EVAR procedure and the penultimate CT scan of the endoleak group were selected as controls using measurements from both endograft limbs (n=21, 3 excluded). Prototype Vascular Imaging Analysis software was adapted to calculate 6 parameters for the distal apposition zone: fabric distance, shortest apposition length, endograft diameter, iliac seal surface (ISS), iliac endograft apposition surface (IEAS), and percentage of iliac surface coverage (IEAS/ISS × 100). Measurements were performed on the preoperative, first postoperative, and penultimate/matched follow-up CT scans. Interobserver variability was assessed with the intraclass correlation coefficient (ICC). Continuous data are presented as the median [interquartile range (IQR) Q1, Q3]. **Results:** CTA follow-up was not significantly different between the endoleak and control groups [30 months (IQR 18, 58) vs 36 months (IQR 21, 59), p=0.843]. Interobserver agreement was good to excellent for all parameters (ICC 0.879–0.985). Preoperative anatomy and endograft dimensions on the first follow-up CTA scan did not differ significantly between the groups. When the penultimate CTA scan was compared with the first postoperative CT scan, endograft dimensions had significantly changed in the endoleak group; importantly, apposition was significantly decreased, and fabric distance was significantly increased, indicating limb retraction. Differences in changes in endograft dimensions were significant between the groups. **Conclusion:** New CT-applied software was introduced to visualize apposition and position changes of endograft limbs during follow-up. The software demonstrated good-to-excellent interobserver agreement and enabled accurate analysis of post-EVAR endograft dimensions. Significant changes in apposition and position were observed with the software on the penultimate CT scan prior to diagnosis of type Ib endoleak.

Keywords

abdominal aortic aneurysm, apposition, computed tomography angiography, endograft limb, endoleak, endovascular aneurysm repair, iliac limb, position change, type Ib endoleak, stent-graft

Introduction

Abdominal aortic aneurysms (AAAs) are frequently treated by endovascular means.[1,2] Follow-up after endovascular aneurysm repair (EVAR) is regularly performed with computed tomography angiography (CTA) scans.[1] Because of hemodynamic forces acting on the endograft, subtle changes in the position of the endograft may occur that can lead to post-EVAR complications such as migration or endoleak. Type I endoleaks are associated with a

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Table 1. Baseline Anatomical Characteristics of the Endograft Patients and Limbs in the Endoleak and Control Groups.

Variable[a]	Endoleak (12 Patients, 15 Limbs)	Controls (12 Patients, 21 Limbs)	p
Time between CT scan and EVAR,[b] d	55 (28, 65)	41 (22, 96)	0.932
Iliac diameter, mm	17 (15, 23)	16 (14, 18)	0.170
Iliac length,[c] mm	47 (41, 62)	57 (42, 81)	0.279
Graft diameter, mm	16 (16 20)	16 (13, 20)	0.340
Oversizing, %	0 (−12, 10)	1 (−5, 13)	0.340
Maximum AAA diameter,[b] mm	65 (53 71)	62 (54, 72)	0.644
Endografts[b]			0.238
Endurant	7	11	
Zenith	2	1	
Talent	1	0	
AFX	2	0	

Abbreviations: AAA, abdominal aortic aneurysm; CT, computed tomography; EVAR, endovascular aneurysm repair.
[a]Continous data are presented as the median (interquartile range Q1, Q3).
[b]Per patient.
[c]Length from common iliac artery orifice to iliac bifurcation.

continued risk of aneurysm rupture after EVAR.[2,3] A variety of studies have been performed on the loss of proximal apposition of the endograft. However, less attention has been paid to distal endograft fixation, even though a type Ib endoleak may also repressurize the aneurysm and increase the risk of rupture.[4–8]

Accurately quantifying and visualizing the endograft position and apposition during follow-up is essential to prevent late seal failures. Identifying small changes in the position of the endograft, such as tilting, migration, and dilatation of the common iliac artery (CIA) and thereby full expansion of the endograft limb, is challenging with standard CT imaging. The in-house developed, CT-applied Vascular Imaging Analysis (VIA) prototype software (Endovascular Diagnostics, Utrecht, the Netherlands) can determine apposition and the 3-dimensional (3D) position of the endograft during follow-up.[9] The software has been validated to detect (subtle) changes in proximal abdominal aortic endograft position and apposition[9–11] and enabled demonstration of progressive changes in endograft position in the aortic neck before complications became obvious with standard CT imaging.[10] The same methodology can be implemented for iliac endograft limb position and apposition. Hence, the purpose of this study was to validate the new CT-applied software with a focus on endograft limb position and apposition and changes therein during post-EVAR follow-up.

Materials and Methods

Patient Selection and Characteristics

Twelve elective EVAR patients (mean age 81±6 years; 10 men) who had undergone stent-graft extension for a type Ib endoleak were identified in the hospital's database based on the availability of the following imaging studies: a pre-EVAR CTA, a 1-month CTA, and a follow-up CTA prior to the scan that showed the type Ib endoleak. The following endografts were deployed in the endoleak group (Table 1): 7 Endurant (Medtronic, Minneapolis, MN, USA), 1 Talent (Medtronic,), 2 Zenith (Cook, Bloomington, IN, USA), and 2 AFX (Endologix, Irvine, CA, USA). Prior to EVAR, the median maximum AAA diameter was 64.8 mm. Three patients had bilateral type Ib endoleaks for a total of 15 endograft limbs analyzed; the contralateral limb was not included. The CT scan before detection of the type Ib endoleak is hereafter referred to the penultimate CT scan in the endoleak group.

Twelve control patients (mean age 82±7 years; 11 men) without type Ia or Ib endoleaks were selected because they had at least 2 post-EVAR CTAs and a similar interval between the primary EVAR procedure and the penultimate CT scan of the endoleak group. One Zenith and 11 Endurant endografts were used in the control group; the median maximum AAA diameter at baseline was 61.7 mm. Both endograft limbs for the control group were included in the analysis, except for 3 endograft limbs with primary extensions to the external iliac artery. The penultimate CT scan in the endoleak group was compared with the matched follow-up CT scan of the control patients. All CT scans were part of regular EVAR follow-up, and radiologists assessed the scans according to a standardized protocol.

Investigational review board approval was obtained from the St Antonius Hospital (W16.123, 10-10-2016), with exemption from patient consent for review of anonymized CT datasets.

Measurement Protocol

CTA images were acquired on a 256-slice CT scanner with the following scan parameters: 120-kV tube voltage, 0.75-mm slice thickness, 0.9-mm pitch, and 128×0.625-mm

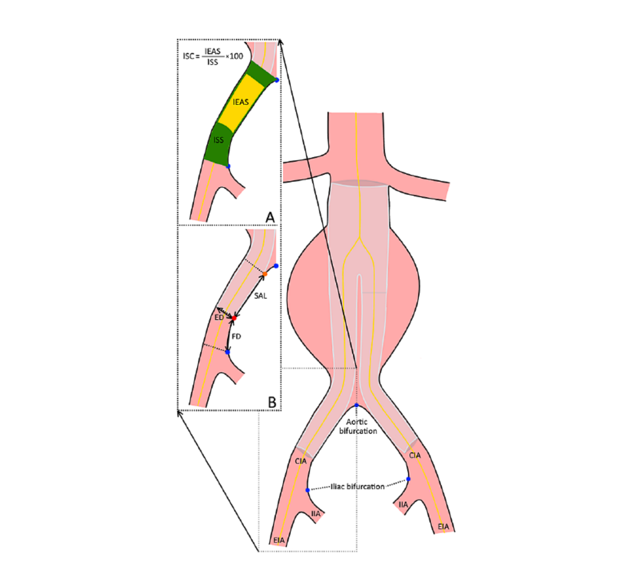

Figure 1. Schematic depiction of an infrarenal abdominal aortic aneurysm with endograft and iliac apposition surfaces. A center lumen line was drawn through the aorta and iliac arteries. Three-dimensional coordinate markers were placed on the renal artery orifices to define the baseline and the aortic and iliac bifurcations (blue dots). (A) The iliac seal surface (ISS), the surface area available for sealing in the common iliac artery (CIA), was defined as the area between the aortic and iliac bifurcation (green area) and the iliac endograft apposition surface (IEAS), the actual apposition of the endograft limb in the CIA (yellow area). The iliac surface coverage (ISC) was defined as IEAS/ISS × 100. (B) The shortest apposition length (SAL), the shortest distance between the proximal (orange dots) and distal (red dots) part of the endograft limb where there is circumferential seal, and the endograft diameter (ED), the average diameter of the distal end of the endograft limb. Fabric distance (FD) is between the iliac bifurcation and the most distal end of the endograft limb. EIA, external iliac artery; IIA, internal iliac artery.

collimation. CTs were acquired in the arterial phase, using bolus triggering with a threshold of 100 Hounsfield units.

Measurements were performed on the preoperative, first postoperative, and the penultimate/matched follow-up CT scans. The endograft limbs of the first postoperative and penultimate/matched CT scans were compared between the groups. In 2 cases selected for illustration, measurements were also performed on the final CT scan that reported the type Ib endoleak.

The 3Mensio Vascular workstation (version 9.0 SP1; Pie Medical, Maastricht, the Netherlands) was used for the measurements. A center lumen line was semiautomatically drawn through the aorta and iliac arteries, and 3D coordinate markers were placed on the renal artery orifices (to define the baseline) and on the aortic and iliac bifurcations. The iliac bifurcation markers were placed just proximal to the orifice of the internal iliac artery (Figure 1, blue dots). On postoperative CT scans, markers were placed on the distal end of the fabric of the implanted iliac endograft limbs to identify the endograft limb position and visualize possible endograft limb retraction. A marker was also placed at the distal and proximal locations where the endograft limb lost circumferential apposition with the CIA (Figure 1A, red and orange dots). Similar to a previous study by Bastos Gonçalves et al,[12] the average outer wall CIA diameter was measured at a fixed distance of 10 mm proximal to the distal end of the endograft fabric on the postoperative CT scan.

VIA prototype software[9–11] that was primarily developed to calculate the proximal endograft apposition within the infrarenal neck was adapted to calculate the iliac apposition zones. The VIA prototype software uses 3D coordinates of anatomical landmarks, the edges of the endograft fabric, the centerline, and a mesh of the lumen, which are exported from the 3Mensio workstation. The software then calculates and visualizes in 3D the apposition surface area, minimal length of apposition, and fabric distances over the curve of the aorta and CIAs, and average diameter of the distal fabric edge (Figure 2).

Definitions and Visualization

All endograft limbs were measured with the VIA prototype software to visualize the endograft limb position and apposition during follow-up. The following postoperative iliac endograft parameters were defined: (1) the iliac seal surface (ISS) area available for sealing in the CIA, defined as the area between the orifice of the CIA and iliac bifurcation (Figure 1A); (2) the iliac endograft apposition surface (IEAS) in the CIA (Figure 1A); (3) the iliac surface coverage (ISC), the percentage of the ISS that was covered by the endograft limb (IEAS/ISS × 100%); (4) fabric distance (FD) over the curve of the CIA between the most distal end of the endograft limb and the iliac bifurcation (Figure 1B); (5) the shortest apposition length (SAL) between the proximal and distal parts of the endograft limb where there is circumferential seal (Figure 1B); and (6) the average endograft (inner) diameter (ED) over the plane perpendicular to the center lumen line through the distal end of the endograft limb (Figure 1B). With the ED, the percentage of endograft limb expansion (as a percentage of the original diameter) was calculated.

Variability Analysis

To analyze the interobserver variability, 2 independent, experienced observers (S.G. and R.S.) performed the centerline reconstructions and measurements on the first postoperative CT scan. Previously described variability of aortic morphology parameters has demonstrated excellent agreement.[13] Hence, this study analyzed only the variability

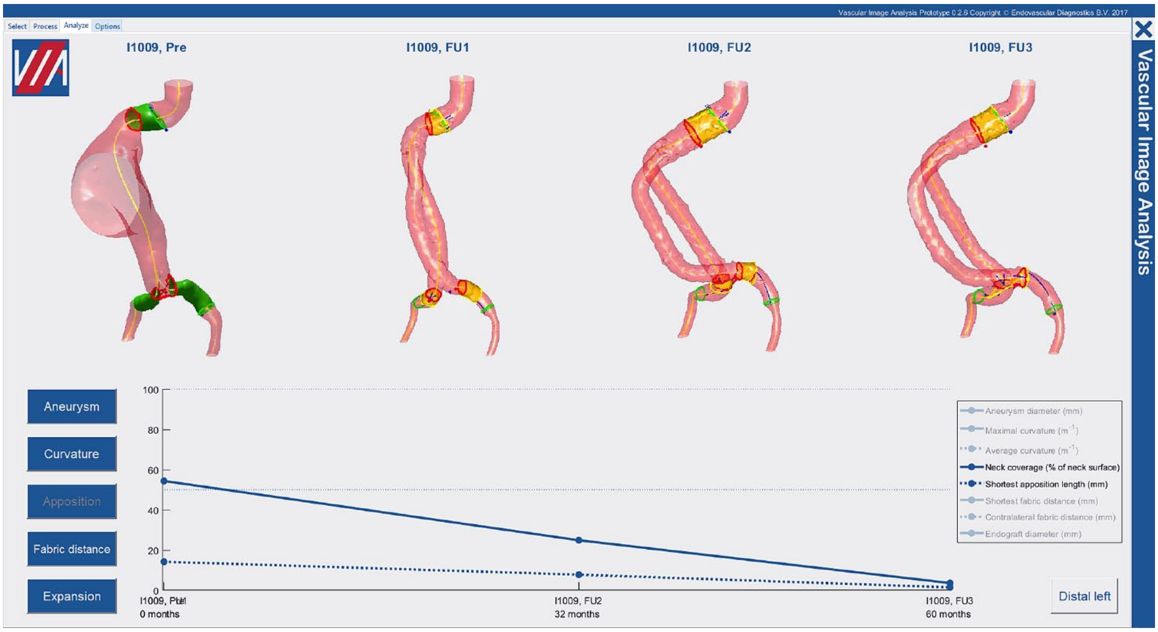

Figure 2. Overview of pre- and post-endograft computed tomography (CT) analysis in VIA prototype software. The 3-dimensional (3D) coordinates of the anatomical landmarks, the edges of the endograft fabric, the centerline, and a mesh of the aortic lumen are exported from a vascular workstation. Apposition surface areas (yellow), shortest apposition lengths, fabric distances, and fabric edge diameters are calculated automatically from these 3D coordinates. Changes in apposition, fabric distance, or endograft expansion measured at the distal end of the endograft limb are displayed in the software for consecutive CT scans. In this example, the decrease of apposition surface (solid line) and shortest length of apposition (dotted line) are displayed for the distal left limb. The proximal apposition was stable, while distal apposition decreased in both limbs.

regarding the previously defined iliac parameters (ie, ISS, IEAS, ISC, SAL, ED, and FD).

Statistical Analysis

Normality of the data was tested; because most were non-normally distributed, the outcomes are presented as median with interquartile range (IQR: Q1, Q3). Differences in continuous variables between the endoleak and control groups were tested with the nonparametric Mann-Whitney *U* test. Differences between first and penultimate/matched follow-up CTAs were analyzed with the Wilcoxon signed-rank test. Differences in endografts were assessed with the Pearson chi-square test.

The intraclass correlation coefficient (ICC) was used to determine the interobserver agreement. The ICC was tested with a 2-way mixed model by absolute agreement and is expressed with the 95% confidence interval (CI). ICC values >0.8 indicated good agreement. The repeatability coefficient (RC) was defined as 1.96 times the standard deviation of the difference between the paired measurements. P values were considered significant when the 2-tailed α was <0.05. Statistical analyses were performed with SPSS software (version 24; IBM Corporation, Armonk, NY, USA).

Results

The baseline anatomical characteristics of the 15 endograft limbs with a type Ib endoleak and the 21 endograft limbs without an endoleak are reported in Table 1. The preoperative median outer wall CIA diameter was 16.8 mm vs 15.6 mm in the endoleak and control groups, respectively. The endograft limb size was a median of 16 mm in the endoleak group and 16 mm in the control group. Median endograft limb oversizing was 0% vs 1% in the endoleak and control groups, respectively. Preoperative, first, and penultimate/matched follow-up CT images had a median slice thickness of 2.0 mm (IQR 1.5, 3.2), 1.5 mm (IQR 1.5, 3.0), and 1.5 mm (IQR 1.5, 1.5), respectively.

Variability Analysis

Interobserver variability was analyzed for all included endograft limbs (Table 2). There was good agreement for the ED (ICC 0.879); the remaining variables demonstrated

Table 2. Interobserver Variability for the Apposition and Seal Parameters of the 36 Endograft Limbs.

	First Postoperative CT (Observer 2 – Observer 1)				
Variable	Mean[a]	Difference[b]	RC	ICC (95% CI)	p
ISS, mm^2	2409	121	541	0.985 (0.970 to 0.992)	<0.001
IEAS, mm	1349	142	529	0.976 (0.953 to 0.988)	<0.001
ISC, %	55.6	2.9	15.1	0.964 (0.930 to 0.982)	<0.001
SAL, mm	19.5	1.2	9.0	0.968 (0.937 to 0.984)	<0.001
ED, mm	16.8	1.3	5.4	0.879 (0.763 to 0.938)	<0.001
FD, mm	16.4	−0.1	7.7	0.959 (0.920 to 0.979)	<0.001

Abbreviations: CI, confidence interval; ED, endograft diameter; FD, fabric distance; ICC, intraclass correlation coefficient; IEAS, iliac endograft apposition surface; ISC, iliac surface coverage; ISS, iliac seal surface; RC, repeatability coefficient; SAL, shortest apposition length.
[a]Mean value measured by 2 observers.
[b]Mean difference between paired measurements.

Table 3. Endograft Limb Dimensions on First Postoperative Computed Tomography Scans in the Endoleak and Control Groups.[a]

Variable	Endoleak (12 Patients, 15 Limbs)	Controls (12 Patients, 21 Limbs)	p
Follow-up,[b] d	43 (28, 50)	36 (29, 43)	0.887
Maximum AAA diameter,[b] mm	63 (54, 70)	62 (56, 74)	>0.99
Iliac diameter, mm	17 (16, 22)	16 (15, 19)	0.136
Endograft limb expansion, %	100 (100, 100)	100 (86, 100)	0.141
FD, mm	17 (8, 22)	13 (8, 24)	0.665
Apposition			
IEAS, mm^2	836 (466, 1410)	1025 (783, 2093)	0.180
ISC, %	52 (43, 69)	64 (49, 72)	0.642
SAL, mm	15 (8, 25)	16 (13, 30)	0.127

Abbreviations: AAA, abdominal aortic aneurysm; FD, fabric distance; IEAS, iliac endograft apposition surface; ISC, iliac surface coverage; SAL, shortest apposition length.
[a]Data are presented as the median (interquartile range Q1, Q3).
[b]Per patient.

excellent agreement (ICC 0.959–0.985). The average difference between the observers for the ISS and IEAS was 121 mm^2 (RC 541 mm^2) and 142 mm^2 (RC 529 mm^2), respectively. When this was expressed as the percentage of the mean calculated value, the mean difference was within 5.0% for the ISS and 10.6% for the IEAS; 95% of the variability of both surfaces was within 22.5% to 39%, respectively. SAL, ED, and FD were calculated with mean interobserver differences of 1.2 (RC 9.0), 1.3 (RC 5.4), and −0.1 (RC 7.7) mm, respectively. Of these variables, 95% of the variability in calculating these distances was within 0.4% to 7.8%.

Group Comparison

The endograft limb dimensions of the first postoperative CT scans are reported in Table 3. The duration from EVAR to the first follow-up CTA was not significantly different between the groups. On the first post-EVAR CTA, 100% (IQR 100%, 100%) of the endograft limbs were fully expanded in the endoleak group and 100% (IQR 86%, 100%) were fully expanded in the control group. The median IEAS was 836 mm^2 (IQR 466, 1410) in the endoleak group and 1025 mm^2 (IQR 783, 2093) in the control group; a similar part of the CIA was covered in both groups, and the SAL was comparable.

The penultimate/matched follow-up endograft parameters are reported in Table 4. The interval between EVAR and the penultimate/matched follow-up CT imaging was 30 months (IQR 18, 58) in the endoleak group vs 36 months (IQR 21, 59) in the controls (p=0.843). The iliac diameter increased to 21.7 mm (IQR 18.7, 27.0) in the endoleak group and to 17.5 mm (IQR 15.8, 21.0) in the control group, which was significantly different between the groups (p=0.012). At follow-up CTA, 100% (IQR 100%, 100%) of endograft limbs in the endoleak group and 100% (IQR 88%, 100%) in the control group were expanded to their maximum (fabric) diameter. Aortic aneurysm sac regression (>0 mm) was observed in 25% of the patients with type Ib endoleaks and in 67% of controls. Aortic aneurysm growth (>5 mm) was observed in 75% vs 0% for the endoleak and control groups, respectively. Proximal displacement of the

Table 4. Endograft Limb Dimensions on the Penultimate/Matched Follow-up Computed Tomography Scans in the Endoleak and Control Groups.[a,b]

Variable	Endoleak (12 Patients, 15 Limbs)	Controls (12 Patients, 21 Limbs)	p
Follow-up,[c] d	30 (18, 58)	36 (21, 59)	0.843
Maximum AAA diameter,[c] mm	78 (66, 87)	55 (48, 67)	0.003
Iliac diameter, mm	22 (19, 27)	18 (16, 21)	0.012
Endograft limb expansion, %	100 (100, 100)	100 (88, 100)	0.537
FD, mm	28 (11, 41)	18 (7, 27)	0.048
Apposition			
IEAS, mm^2	89 (0, 272)	1270 (802, 2278)	<0.001
ISC, %	5 (0, 15)	49 (37, 64)	<0.001
SAL, mm	1 (0, 3)	15 (10, 24)	<0.001

Abbreviations: AAA, abdominal aortic aneurysm, FD, fabric distance; IEAS, iliac endograft apposition surface; ISC, iliac surface coverage; SAL, shortest apposition length.
[a]Data are presented as the median (interquartile range Q1, Q3).
[b]The penultimate computed tomography (CT) scan for the endoleak group was the scan before the one disclosing the endoleak; the matched scan in the control group had a similar interval between the primary stent-graft procedure and the penultimate CT scan of the endoleak group.
[c]Per patient.

Table 5. Change in Endograft Limb Dimensions Between the Penultimate/Matched and First Postoperative Computed Tomography Scans in the Endoleak and Control Groups.[a,b]

Variable	Endoleak (12 Patients, 15 Limbs)	Controls (12 Patients, 21 Limbs)	p
Maximum AAA diameter,[c] mm	13 (0, 18) p=0.045	−9 (−13, 1) p=0.034	0.003
Iliac diameter, mm	3 (2, 7) p=0.001	1 (1, 3) p=0.001	0.006
Endograft limb expansion, %	0 (0, 0) p=0.109	0 (0, 13) p=0.008	0.096
FD, mm	6 (2, 11) p=0.001	3 (−1, 4) p=0.068	0.026
Apposition			
IEAS, mm^2	−721 (−1342, −171) p=0.002	−13 (−283, 250) p=0.715	<0.001
ISC, %	−42 (−57, −25) p=0.002	−5 (−11, 3) p=0.063	<0.001
SAL, mm	−10 (−19, −6) p=0.001	−3 (−6, 1) p=0.014	0.003

Abbreviations: AAA, abdominal aortic aneurysm, FD, fabric distance; IEAS, iliac endograft apposition surface; ISC, iliac surface coverage; SAL, shortest apposition length.
[a]Data are presented as the median (interquartile range Q1, Q3) and p value for difference between the late and first scans.
[b]The penultimate computed tomography (CT) scan for the endoleak group was the scan before the one disclosing the endoleak; the matched scan in the control group had a similar interval between the primary stent-graft procedure and the penultimate CT scan of the endoleak group.
[c]Per patient.

endograft limb was observed in both groups when compared with the first CT imaging. There was a significant difference in FD between the endoleak and control groups [28 mm (IQR 11, 41) vs 18 mm (IQR 7, 27), p=0.048]. The IEAS was significantly different between the endoleak and control groups [89 mm^2 (IQR 0, 272) vs 1270 mm^2 (IQR 802, 2278), p<0.001], and a significant difference between the ISC of both groups [5% (IQR 0%, 15%) vs 49% (IQR 37%, 64), p<0.001)] was found on late CT imaging. The ISC was significantly decreased in the endoleak group, which was also reflected by a reduction in SAL.

The changes in endograft limb dimensions between the penultimate/matched follow-up of the first postoperative scans are reported in Table 5. The difference in AAA change during follow-up was significant; the AAA diameter increased in the endoleak group, whereas a decrease in diameter was observed in the control group. The median increase in iliac diameter was larger in the endoleak group than in the control group [3 mm (IQR 2, 7) vs 1 mm (IQR 1, 3), p=0.006]. A median FD change of 6 mm (IQR 2, 11) vs 3 mm (IQR −1, 4) was observed in the endoleak and control groups, respectively (p=0.026). In addition, apposition surface, coverage, and length demonstrated significant changes during follow-up in the endoleak group [IEAS −721 mm^2 (IQR −1342, −171), p=0.002; ISC −42% (IQR −57%, −25%), p=0.002; SAL −10 mm (IQR −19, −6), p=0.001], which was significantly different from the control group [IEAS −13 mm^2 (−283, 250), p<0.001; ISC −5% (IQR −11%, 3%), p<0.001; SAL −3 mm (IQR −6, 1 mm), p=0.003].

Since the matched CT for the 12 control patients analyzed in this study, 2 have died, 3 had not yet received

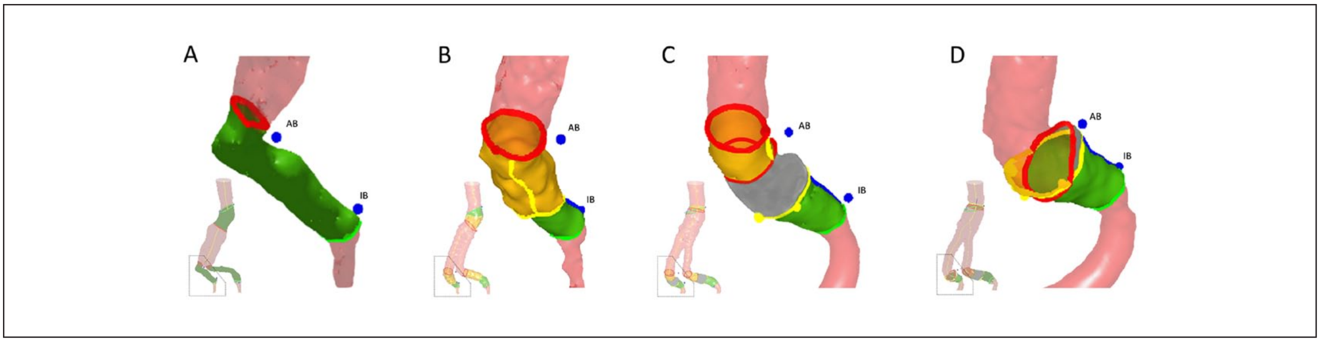

Figure 3. Left endograft limb position and apposition in a common iliac artery (CIA) during follow-up. (A) Preoperative computed tomography (CT) scan with the iliac seal surface. (B) First postoperative CT scan showing the initial apposition. (C) Late CT follow-up on which the type Ib endoleak had not yet been identified. Notice the gray area where the endograft limb does not have circumferential apposition with the arterial wall. A significant loss of seal is present because of an increase in CIA diameter. (D) CT scan before the reintervention for a type Ib endoleak. There appears to be some surface coverage; however, that is only on one side of the CIA. Therefore, the shortest apposition length is 0 mm, and there is no apposition of the endograft limb. AB, aortic bifurcation; IB, iliac bifurcation.

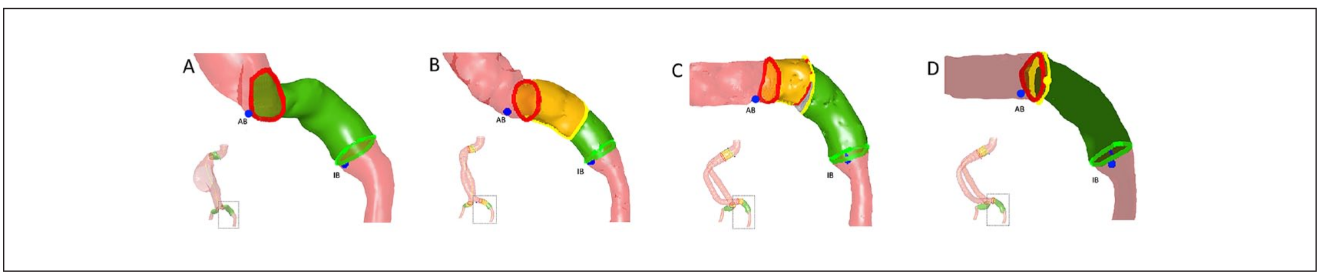

Figure 4. Endograft limb position and apposition of a retracting limb. (A) Preoperative computed tomography (CT) scan with the iliac seal surface. (B) First postoperative CT scan showing the initial apposition. Endograft limb expansion is already 100%. (C) Late CT follow-up on which the type Ib endoleak had not yet been identified. Notice that the endograft limb markers (yellow line) has shifted upward toward the aneurysm sac (ie, the endograft limb is retracting). This is more clearly represented by the increasing fabric distance. Moreover, the endograft limb does not have apposition with the arterial wall (the small gray area) due to the angle of the endograft limb with the common iliac artery (CIA). A significant loss of seal is present because of the retraction of the endograft limb. (D) The CT scan before the reintervention. The iliac surface coverage has decreased to 4%, the shortest apposition length is merely 2 mm, and the fabric distance increases further. The apposition length is 0 mm (red arrow), and a type Ib endoleak is present. AB, aortic bifurcation; IB, iliac bifurcation.

follow-up since the matched scan, and the remaining 7 patients did not have reported complications at the distal sealing zones after a median of 17 months (IQR 15, 21).

Case Examples

A patient was electively treated for a 56-mm AAA using an Endurant endoprosthesis (Figure 3A) with bilateral 16-mm-diameter endograft limbs. Effective proximal and distal seal were reported at 50 days (Figure 3B), with 73% and 62% coverage of the right and left CIAs, respectively, and full expansion of both endograft limbs. At 61 months, a type Ia endoleak was suspected on CTA because of an increase in AAA diameter to 65 mm, which was confirmed by subsequent digital subtraction angiography. During reintervention, the proximal seal was successfully extended with a 36-mm aortic cuff (Endurant). At 64 months (Figure 3C), the right iliac diameter had increased to 22 mm, which resulted in a major decrease in IEAS and SAL. The FD increased from 14 to 17 mm (ie, the endograft limb retracted 3 mm); there was no sign of an endoleak. At 77 months (Figure 3D), the aneurysm sac diameter had grown progressively to 78 mm, and a type Ib endoleak had been detected. The IEAS was down to 8%, and the SAL had decreased to 0 mm. In addition, the limb was retracted by 7 mm compared with the first postoperative scan.

A second patient was treated for a symptomatic 123-mm AAA; an Endurant endoprosthesis with 16-mm-diameter limbs (Figure 4A) was deployed. Both CIAs were 16 mm, resulting in full expansion of the endograft limbs on the first postoperative CT scan (Figure 4B). For the left endograft limb, the ISC was 60%, with adequate proximal and distal seal. At 31 months (Figure 4C), the FD had increased to 36 mm, thus the endograft limb was retracted by 22 mm. Consequently, the SAL, IEAS, and ISC had decreased significantly, but no endoleak was detected. At 59 months (Figure 4D), the limb retracted further by 12 mm, resulting in a confirmed type Ib endoleak.

Discussion

This study validated CT-applied software for the quantification of expansion, position, and apposition of endograft limbs in the CIA. Interobserver agreement was high for all parameter measurements, with variability similar to measurements in the infrarenal aortic neck.[13,14]

Adequate distal fixation and seal of the endograft limb in the CIA is essential to prevent type Ib endoleak. Seal may be compromised by dilatation of the CIA or by limb retraction.[4,6–8,12,15–18] Expansion of the endograft limb within the CIA, displacement of the endograft limb, as well as the resulting loss of apposition, can be precisely quantified and visualized with the VIA prototype software.

Full endograft limb expansion was observed in all patients in the complication group and in most of the control group, which was the result of almost no oversizing of the endograft limbs compared with the preoperative CIA diameter. Oversizing of the endograft limbs by 10% to 15% could reduce the risk of type Ib endoleak because the radial force will create more stability and seal in the distal landing zone.[8,12,19] Excessive oversizing, however, may increase the risk of CIA dilatation and fabric infolding.[12,20] Progressive dilatation of the iliac diameter beyond the endograft limb diameter can lead to detachment of the endograft limb and seal failure. Longer seal zones may better endure progressive dilatation and may protect against seal failure.

It is important to note that there are differences in sealing mechanisms between the limbs of different endograft types. For example, the apposition of a Zenith endograft limb may be smaller than that of an Endurant endograft limb. This study investigated the differences within each patient during follow-up, with the first postoperative CT scan acting as that patient's control scan for comparison during follow-up. Change in apposition of each patient during follow-up is very relevant. However, the apposition zones of different endograft limbs cannot be directly compared to each other, and a one on one comparison should be performed only for the same endograft models.

Significant position changes were observed on the penultimate CT scan before endoleak diagnosis. The distance between the fabric and the origin of the internal iliac artery increased significantly for both groups, but the increase in the endoleak group was double that in the control group. If endograft limbs in the control group continue to displace, type Ib endoleak may also develop in these patients during later follow-up. Therefore, this study is limited regarding the duration of follow-up, and type Ib endoleaks may even occur in the control group. Currently, all patients are under strict duplex ultrasound follow-up.

In this study, the seal is represented by a percentage because it is both intuitive as well as comparable within a patient. It also demonstrates the apposition of the CIA that could have been utilized. Maybe this percentage of coverage can serve as a risk factor for late complications; a larger clinical study will be performed to identify risk factors for late type Ib endoleaks. Longer distal seal zones (>15 mm), coverage of at least 70% of the iliac seal zone, and deployment of the endograft limb within 10 mm of the internal iliac artery protect against proximal migration of the endograft limb and type Ib endoleak.[4,6,8,12,21] In this study, however, no significant changes were observed between the endoleak and control groups for seal zone length, CIA coverage, or deployment accuracy on the first postoperative CT scan. This suggests that the 1-month CT scan is good for identifying acute failures (which were not included in this study) and for defining a postoperative baseline for endograft dimensions. A second postoperative CT scan is essential for detecting changes from this baseline that may precede later seal failure.

An increase in the CIA diameter beyond the endograft limb diameter and retraction of the endograft limb results in loss of apposition, which could be clearly quantified and visualized with the VIA prototype software. Contrary to the control patients, apposition was largely lost in all patients in the endoleak group before the endoleak could be detected. Endograft limb extension to the internal iliac artery could be considered based on loss of apposition, before urgent repair of a repressurized aneurysm is required; however, no clear cutoff values can yet be provided for when to intervene before a type Ib endoleak is clearly visible.

Hostile iliac anatomy may increase the risk of apposition loss, particularly due to limb retraction. Although hostile anatomy has been investigated extensively in the infrarenal aortic neck and has been associated with endograft migration and type Ia endoleak,[22] a clear definition of hostile iliac seal zone criteria is lacking.[23,24] Hostile CIA criteria that are associated with distal complications, such as type Ib endoleak and limb occlusion, may provide a better understanding of long-term EVAR patency. The AAA volume was not measured in this study. While unfavorable anatomy and implanted devices may influence the risk for type Ib endoleak,[8,12] this study was not designed to find predisposing factors that increase the risk for distal seal failure.

Limitations

This study is retrospective with small numbers of patients. A large clinical study with a larger group of patients is needed to identify relevant cutoff values that indicate later seal failure and patients who require preventive reinterventions.

The VIA prototype software is still an investigational product and not yet licensed for clinical use. The dedicated post-EVAR analysis requires about 7 minutes of extra time to draw a centerline and to retrieve and process the coordinates. Similar to preoperative sizing measurements in a vascular workstation, accuracy of dedicated post-EVAR analysis is limited by the quality of the CT scan and sufficient contrast in the limbs.

Conclusion

New CT-applied software was introduced to visualize apposition and position changes of aortic endograft limbs during follow-up. The software demonstrated good-to-excellent interobserver agreement and enabled accurate analysis of post-EVAR endograft limb dimensions. Significant changes in apposition and position were observed on the penultimate CT before the diagnosis of type Ib endoleak. A larger prospective patient study comparing groups with and without late distal complications is needed to demonstrate whether it can predict type Ib endoleaks on a large scale.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Jean-Paul de Vries and Richte Schuurmann are cofounders of Endovascular Diagnostics B.V., which holds patent rights to the VIA software used in this study.

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