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Efficacy of volumetric analysis of aorta as surveillance tool after EVAR

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Summary   *Objective:* Compared to the diameter measurement, volume measurement of the aneurysm can be an alternative option for accurate evaluation. This study was undertaken to analyze the relationship between the diameter and the volume measurement of the aorta after EVAR.

Methods: From January 2012 to December 2016, 82 patients underwent EVAR in our institution. The infrarenal aorta after EVAR was evaluated with regard to maximal aortic diameter (DMAX) and aortic volume. The relationship between the DMAX and the aortic volume measurement after EVAR were analyzed.

Results: The rate of enlargement of aortic volume with endoleak over time was 0.02 cm^3/month. The rate of enlargement of DMAX with endoleak over time was 0.007 mm/month. The mean rate of enlargement of aortic volume was significantly different from the mean enlargement rate of DMAX (p = 0.02). A $\geq$12% of increase rate of aortic volume was equivalent to an increase of $\geq$5 mm in the DMAX after EVAR.

Significantly more endoleak occurred in the DMAX-enlargement group than no-enlargement group (100% vs. 26.76%, p < 0.001). Significantly more patients need secondary intervention and treatment of endoleak in the DMAX-enlargement group (p = 0.02 and p < 0.001, respectively). Significantly more endoleak occurred in the aortic volume—enlargement group than no-enlargement group (90.91% vs. 16.67%, p < 0.001). Significantly more patients needed secondary intervention and treatment for endoleak in the aortic volume—enlargement group (p = 0.02 and p < 0.001, respectively).

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Conclusion: Volumetric analysis can predict successful EVAR more accurate than diameter measurement. A $\geq$12% increase in aortic volume was equivalent to a $\geq$5 mm increase in aortic diameter.

1. Introduction

Endovascular aneurysm repair (EVAR) needs surveillance following the procedure. Serial measurement of aortic diameter has been one of the main modalities for the evaluation of the risk of rupture.

Shrinkage of the excluded aneurysmal sac and the absence of any types of endoleak are generally considered indicators of a successful EVAR, and the vast majority of published studies focus on maximal aortic diameter (DMAX) changes and the presence or absence of endoleaks.[1,2] Nevertheless, it is undeniable that a number of excluded aneurysms continue to expand without detectable endoleak and have a continual risk of rupture. In this case, there is an urgent need for more accurate and more reliable post-procedure surveillance parameters by which to assess the behavior of excluded aneurysms. Theoretically, and as has been proved by other studies,[3,4] measuring the volume of aneurysm would make more sense than using DMAX measurements.

This study was made to evaluate the results of EVAR depending on endoleaks and an analysis of the relationship between the diameter and the volume measurement of the aorta after EVAR.

2. Methods

This study was approved by the appropriate Institutional Review Board (IRB No. KC18RESI0007). Written informed consent for the procedures was obtained from all patients or their families. This was a retrospective study from prospectively registered data of patients who admitted with abdominal aortic aneurysm (AAA) or AAA combined with common iliac artery aneurysm (CIAA) or isolated CIAA and who underwent EVAR from January 2012 to December 2016. We performed reviews of patients' demographics and of the pre- and post-procedure non-contrast or contrast-enhanced computed tomography angiography (CTA) scans or magnetic resonance angiography (MRA) from the electric medical records (EMR) and PACS. All the patients of this study were prescribed a CTA or MRA before EVAR in order to determine treatment options, and all had at least one CT scan or MRA after EVAR.

The patient's inclusion criteria for this study was patients with diameter greater than 50 mm in AAA, diameter greater than 20 mm in unilateral or bilateral CIAA combined with AAA (diameter greater than 50 mm), diameter greater than 30 mm in isolated unilateral or bilateral CIAA who underwent EVAR. The exclusion criteria were patients with isolated external or internal iliac artery aneurysm and those who underwent open surgical aneurysm repair.

Pre-procedure and post-procedure CT imaging or MRA data of all patients were obtained in the format of Digital Imaging and Communications in Medicine (DICOM) and had a slice thickness range of 2–5 mm. All the measurements of lengths and angles were calculated along the lumen centerline. The diameter measurements were made from outer wall to outer wall at a right angle to the lumen centerline in a target plane. The DMAX enlargement was defined as a DMAX post-EVAR measurement that was $\geq$5 mm larger than the pre-EVAR measurement.

Volumes were obtained by loading DICOM format images on the Aquarius iNtuition Client Viewer version 4.4.11.82 (Terarecon, Foster City, CA, USA), which was used in the summation of area technique. The target region was included by drawing lines along the outer aortic wall manually at several different levels throughout the abdominal aorta from the most caudal renal artery to the native aortic bifurcation. After that, the Aquarius iNtuition Client Viewer identified and included similar voxel intensity values of regions in the remaining sections automatically. At last, after being properly revised or checked by the operator, the target region volume was obtained. The aortic volume change rate was needed to analyze its relationship with DMAX changes after the procedure. The formula for calculating the aortic volume change rate was $(V2 - V1)/V1 \times 100$. In this formula, V1 means the initial aortic volume before EVAR, V2 means the largest volume of the aorta during post-EVAR surveillance. If the calculated aortic volume change rate was a positive number, this showed that the aortic volume increased after EVAR. If it was negative number, the aortic volume was understood to have been reduced. The smaller absolute value of the aortic volume change rate was, the less the amount of change there was in the aortic volume. Similarly, The formula for calculating the aortic diameter change rate was $(D2 - D1)/D1 \times 100$.

Definition of the non-instructions for use (IFU): 1. Neck diameter <18 mm or >32 mm 2. Neck length <15 mm (distance between the lowest renal artery and the origin of the aneurysmal dilation of the aorta). 3. Infrarenal neck angulation (α) >60° (angle calculated between lines of the long axis of the infrarenal neck and the long axis of the aneurysm sac). Suprarenal neck angulation (β) >45° (angle calculated between lines of the long axis of the suprarenal aorta and the long axis of the infrarenal neck). 4. Neck thrombus or calcification covering >50% of the aneurysm neck circumference. 5. Conical neck (diameter dilated 10% within 15 mm from the most caudal renal artery). 6. Aortic bifurcation diameter <18 mm 7. Common iliac artery sealing zone diameter <7.5 mm or >20 mm 8. Common iliac artery sealing zone length <20 mm 9. Access artery (common femoral artery and external iliac artery)

diameter<7.5 mm. It was considered non-IFU if one or more of the above mentioned criteria existed on pre-procedure CTA or MRA.

We defined the initial endoleak as any type of endoleak that was detected in the final angiogram of the initial EVAR. Late endoleak was defined as any types of endoleak that was detected during the periods of surveillance after EVAR.

Pre-procedure and post-procedure CT imaging or MRA data were reviewed at one month, six months, 12 months, and on yearly follow-up were reviewed to measure the aortic volume and DMAX and assess the presence of endoleaks or other complications. Endoleaks were classified as major endoleak (type I [proximal or distal sealing zone] or type III [graft disconnection]) and type II endoleak (collateral perfusion).[5,6] In this study, enlargement of the aortic DMAX with undetectable endoleak was defined as type V endoleak.

The criteria for reintervention of the study: major endoleak without any contraindications of procedures, type II endoleak with DMAX enlargement ≥5 mm is observed, stent graft limb occlusion or kinking with relevant symptom, stent graft migration with endoleak was observed.

2.1. Statistical analysis

Since the scale of aortic volume and DMAX were not the same, in the comparison of the effects of endoleak on aortic volume and DMAX, each value was standardized (value-mean/SD). Since the aortic volume and DMAX values were repeatedly measured over time for each individual, we used a mixed model to evaluate the effects of an endoleak on aortic volume and DMAX, considering the correlation between the repeated measurements. The Akaike information criteria (AIC) value was used as a statistic for evaluating the goodness-of-fit of the mixed model, and the model with the smallest value was adopted as an appropriate model. The covariance structure of the mixed model was an autoregressive structure, and the maximum likelihood method was used to estimate the coefficient of the model. We performed a Spearman correlation coefficient analysis to determine the association between the aortic volume change rate and that of the DMAX. We conducted a minimum p-value approach by Fisher's exact test to find the optimal cut-off value for the aortic volume, which was associated with a presence of the DMAX enlargement.[7] The threshold value with the smallest p-value was used as the optimal cut-off value, which was corrected with the Miller and Siegmund method for multiple comparisons.[8] We examined the relationships between enlargement of DMAX or aortic volume and the covariates by χ2 test, Fisher's exact test, t-test, or Wilcoxon rank sum test (Mann−Whitney U test).

SAS version 9.3 (SAS Institute, Cary, NC, USA) was used to perform statistical analyses. A p-value of less than 0.05 was considered to be statistically significant (two-tailed).

3. Results

Table 1 shows the effects of the predictors on aortic volume and DMAX over time. The enlargement rate of aortic volume with endoleak over time was 0.02 (=−0.007 + 0.027) cm^3/month. The enlargement rate of DMAX with endoleak was 0.007 (=−0.009 + 0.016) mm/month. The enlargement rate of aortic volume was significantly different from the enlargement rate of DMAX (p = 0.02 by Wilcoxon ran-sum test) (Table 2). There was a relatively strong correlation between the enlargement rate of aortic volume and DMAX, that is, the larger the volume increases, the larger the DMAX increases (the Spearman correlation coefficient was 0.8154) (Table 2). By the minimum p-value approach, we estimated the optimal cut-off value of the increased rate of aortic volume as 12% with the smallest p-value, which was corrected with the Miller and Siegmund method for multiple comparisons.[8] Under the circumstances, the p-value of the relationship between the DMAX enlargement (≥5 mm) and the increase rate of the aortic volume ≥12% was 1.176E-06. Thus, a result was obtained from a statistical method of minimum p-value approach by Fisher's exact test, that is, a rate of increase in aortic volume ≥12% was equivalent to an increase of ≥5 mm in the DMAX after EVAR. Thus, aorta volume enlargement was defined as a rate of increase in aortic volume ≥12% in any period after EVAR.

One hundred and six patients were identified for treated aneurysm, and 82 (61 male, 21 female) underwent EVAR (including 10 who underwent emergency EVAR) in our single institution, and these were reviewed for 21.02 ± 17.59 months of follow-up duration (Table 3). The types of aneurysms encountered were listed in Table 3. A total of 79.27% of the patients were outside of IFU (Table 4). Conventional EVAR was performed in 40.24% of patients, and 59.76% of patients underwent EVAR with adjunctive procedures (Table 5). Endoleaks after initial EVAR occurred in 36.59% of cases, including 13 cases of initial endoleaks and 17 cases of late endoleaks. The secondary intervention rate was 23.17%. In 8.5% of cases, there was aneurysm-related mortality (ARM), and 17.1% of cases experienced non-ARM (Table 6).

Table 1 The effect of the predictors on aortic volume and DMAX over time by the linear mixed model[a].

	Aortic volume			DMAX		
	Beta estimate	SE	P-value	Beta estimate	SE	P-value
With endoleak	0.290	0.2096	0.17	0.521	0.2089	0.01
Time	−0.007	0.0040	0.08	−0.009	0.0032	<0.01
Interaction between endoleak and time	0.027	0.0057	<0.001	0.016	0.0045	<0.001

DMAX: maximal aortic diameter.
[a] Each model was fitted on the standardized (Value-mean/SD) aortic volume and DMAX, respectively.

Table 2 Correlation between the aortic volume and DMAX change rates.

Variable	N	Mean (SD)	Median (IQR)	P-value[a]	Correlation coefficient	P-value[b]
Aortic volume change rate (%)	82	8.05 (28.30)	4.00 (−0.25−13.25)	0.02	0.8154	<0.001
DMAX change rate (%)	82	0.82 (11.82)	0.00 (0.00−3.25)			

DMAX: maximal aortic diameter.
[a] P-value by Wilcoxon ran-sum test.
[b] P-value by Spearman correlation coefficient analysis.

3.1. The DMAX enlargement vs. No enlargement

The DMAX enlargement occurred in 13.41% of patients, whereas there was no enlargement of DMAX in 86.59% of patients after EVAR (Table 3). The mean age of patients differed significantly between the DMAX-enlargement group and the no-enlargement group (80.18 years vs. 75.03 years, p = 0.04) (Table 3). Patients in the DMAX no-enlargement group were more likely to have a hyperlipidemia than patients in the DMAX-enlargement group (46 patients, 64.79% vs. 3 patients, 27.27%, p = 0.02) (Table 3). There were no significant differences in various parameters of IFU between the DMAX-enlargement group and the no-enlargement group except the suprarenal aortic neck angle non-adherence to IFU (β > 45°) (6, 54.55% vs. 13, 18.31%, p = 0.02) (Table 4). The occurrence of endoleaks between the DMAX-enlargement group and the no-enlargement group was significantly different (11, 100% vs. 19, 26.76%, p < 0.001) (Table 6). There was significant difference (p < 0.001) in the time of the endoleak occurrence between the DMAX-enlargement group (initial endoleak 2, 18.18%, late endoleak 9, 81.82%) and no-enlargement group (initial endoleaks 11, 15.49%, late endoleaks 8, 11.27%) (Table 6). Between the DMAX-enlargement group and the no-enlargement group, there was a significant difference in occurrence of initial and late major endoleaks (p = 0.02 and p < 0.001, respectively) (Table 6). Significantly more patients need secondary intervention and treatment for endoleaks in the DMAX-enlargement group than in the DMAX no-enlargement group (p = 0.02 and p < 0.001, respectively) (Table 6).

3.2. The aortic volume enlargement vs. No enlargement

Aortic volume enlargement occurred in 26.83% of patients, while 73.17% of patients experienced no enlargement of aortic volume after EVAR (Table 3). There was a significant difference between the mean age of patients in the aortic volume−enlargement group and that of patients in the no-enlargement group (79.45 years vs. 74.35 years, p = 0.02) (Table 3). Patients in the aortic volume−enlargement group had lower mean BMI than those in the no-enlargement group (21.59 vs. 23.35, p = 0.03) (Table 3). There were no significant differences in various parameters of IFU between the aortic volume−enlargement group and the no-enlargement group except the suprarenal (β > 45°) and infrarenal aortic neck angle non-adherence to IFU (α > 60°) (p = 0.02 and p < 0.01, respectively) (Table 4). There was a significantly different rate of occurrence of endoleaks between the aortic volume−enlargement group and the no-

enlargement group (20, 90.91% vs. 10, 16.67%, p < 0.001) (Table 6). There was significant difference (p < 0.001) in the time of occurrence of endoleaks between the aortic volume−enlargement group (initial endoleaks 10, 45.45%, late endoleaks 10, 45.45%) and the no-enlargement group (initial endoleaks 3, 5.00%, late endoleaks 7, 11.67%) (Table 6). There was significant difference in occurrence of late major endoleaks between the aortic volume−enlargement group and the no-enlargement group (6, 27.27% vs. 0, p < 0.001) (Table 6). Significantly more patients needed secondary intervention and treatment for endoleaks in the aortic volume−enlargement group than in the no-enlargement group (p = 0.02 and p < 0.001, respectively) (Table 6).

4. Discussion

The durability of EVAR is still the issue of greatest concern, and this is related to issues such as sac expansion and aortic rupture due to continuous blood pressure into the sac through endoleaks. Many post-EVAR ruptures were due to previous complications that needed reintervention to prevent aortic rupture.[9] During post-EVAR surveillance, it is very important to intervene in the sac expansion and endoleaks before a rupture occurs.[10] Therefore, an accurate surveillance tool is needed to improve the prediction and detection of post-EVAR complications, such as endoleak and sac expansion, as early as possible.

Since Balm et al[11] first stated that volume measurement could provide more appropriate assessment in successful EVAR, the reliability of DMAX has been questioned.[12] So far, however, there is still no clear consensus as to how to define the volume change of the aneurysm sac because there is a lack of related research. Several existing studies have different views. Lee et al[1] showed that ≥10% of volume reduction at six months after EVAR could be a reliable predictor of success. Another study expressed a similar opinion.[13] Bley et al[14] proposed that a 2% cutoff value in sac volume changes is an adequate screening test for the assessment of aneurysm stability. Another study showed that ≤0.3% of volume change at six months after EVAR was the strongest independent predictor of endoleaks.[15] Although different methods have been used in the above studies, the same conclusion has been reached that volumetric analysis was a reliable tool for post-EVAR surveillance. In this study, we obtained a result that ≥12% of increase in aortic volume was equivalent to an increase of ≥5 mm in DMAX during surveillance. So the increase in aortic volume was defined as an increase of ≥12% during surveillance after EVAR.

Table 3 Patients' demographics and clinical characteristics according to enlargement of DMAX and aortic volume.

Variables	All (N = 82)	DMAX			Aortic volume		
		Enlargement	No enlargement	P-value	Enlargement	No enlargement	P-value
		11 (13.41%)	71 (86.59%)		22 (26.83%)	60 (73.17%)	
	n (%) or Mean (SD)	n (%) or Mean (SD)	n (%) or Mean (SD)		n (%) or Mean (SD)	n (%) or Mean (SD)	
Age (years)	75.72 (8.95)	80.18 (6.38)	75.03 (9.13)	0.04[a]	79.45 (7.17)	74.35 (9.20)	0.02[a]
Sex				0.27[b]			0.83[c]
Male	61 (74.39)	10 (90.91)	51 (71.83)		16 (72.73)	45 (75.00)	
Female	21 (25.61)	1 (9.09)	20 (28.17)		6 (27.27)	15 (25.00)	
BMI	22.88 (3.35)	21.84 (3.12)	23.04 (3.38)	0.27[d]	21.59 (2.99)	23.35 (3.37)	0.03[d]
DM	13 (15.85)	1 (9.09)	12 (16.90)	1.00[b]	4 (18.18)	9 (15.00)	0.74[b]
HTN	61 (74.39)	8 (72.73)	53 (74.65)	1.00[b]	16 (72.73)	45 (75.00)	0.83[c]
AF	6 (7.32)	2 (18.18)	4 (5.63)	0.18[b]	2 (9.09)	4 (6.67)	0.66[b]
Heart failure	2 (2.44)	1 (9.09)	1 (1.41)	0.25[b]	1 (4.55)	1 (1.67)	0.47[b]
Hyperlipidemia	49 (59.76)	3 (27.27)	46 (64.79)	0.02[b]	10 (45.45)	39 (65.00)	0.11[c]
COPD	32 (39.02)	5 (45.45)	27 (38.03)	0.74[b]	10 (45.45)	22 (36.67)	0.47[c]
Smoking	31 (37.80)	5 (45.45)	26 (36.62)	0.74[b]	9 (40.91)	22 (36.67)	0.73[c]
IHD	36 (43.90)	5 (45.45)	31 (43.66)	1.00[b]	11 (50.00)	25 (41.67)	0.50[c]
CRI	22 (26.83)	2 (18.18)	20 (28.17)	0.72[b]	8 (36.36)	14 (23.33)	0.24[c]
Trauma	2 (2.44)	0	2 (2.82)	1.00[b]	1 (4.55)	1 (1.67)	0.47[b]
Aneurysm type				0.07[b]			0.73[b]
AAA	42 (51.22)	9 (81.82)	33 (46.48)		13 (59.09)	29 (48.33)	
AAA + BICIAA	8 (9.76)	2 (18.18)	6 (8.45)		3 (13.64)	5 (8.33)	
AAA + UNICIAA	16 (19.51)	0	16 (22.54)		3 (13.64)	13 (21.67)	
BICIAA	3 (3.66)	0	3 (4.23)		0	3 (5.00)	
UNICIAA	13 (15.85)	0	13 (18.31)		3 (13.64)	10 (16.67)	

DMAX: maximal aortic diameter, BMI: body mass index, DM: diabetes mellitus, HTN: hypertension, AF: atrial fibrillation, COPD: chronic obstructive pulmonary disease, IHD: ischemic heart disease, CRI: chronic renal insufficiency, AAA: abdominal aortic aneurysm, BICIAA: bilateral common iliac artery aneurysm, UNICIAA: unilateral common iliac artery aneurysm.

[a] P-value from wilcoxon rank-sum test.
[b] P-value by fisher-exact test.
[c] P-value by chi square-test.
[d] P-value by t-test.

DMAX enlargement occurred in 11 cases, and all of them had endoleaks, including two cases of initial endoleaks and nine cases of late endoleaks. Aortic volume enlargement occurred in 22 patients and 20 of them with endoleaks, including 10 cases of initial endoleaks and 10 cases of late endoleaks. The DMAX measurement did not identify the other nine cases of endoleaks caused by aortic volume enlargement. Obviously, the aortic volume enlargement could be a stronger predictor of endoleaks than the DMAX enlargement. Initial and late major endoleaks were associated with DMAX enlargement, whereas late major endoleaks were significantly associated with aortic volume enlargement, and these findings are consistent with those of previous studies.[16] Five of 11 cases of endoleaks in the DMAX-enlargement group underwent reintervention for endoleaks, whereas seven of 20 cases of endoleaks in the aortic volume—enlargement group underwent reintervention for endoleaks. In the aortic volume—enlargement group, there were more patients with endoleaks and more patients needed and underwent reinterventions for endoleaks. Aortic volume enlargement seems to have a closer relationship with

the existence of endoleaks. Therefore, there is a greater need in this case to resolve endoleaks. There was one ARM case in the DMAX-enlargement group, whereas there were two ARM cases and three non-ARM cases in the aortic volume—enlargement group. It had also been indicated in another study that volume measurement may more sensitive to secondary problems than diameter measurement after EVAR.[4] In this study, the rate of ARM (8.5%) was relatively high. Seven cases of ARM were enrolled in this study during surveillance. The rate of ARM were 4.9% (4/82) in 1month, 6.1% (5/82) in 6 months, 7.3% (6/82) in 1 year, and 8.5% (7/82) in 3 years. Four of 7 cases were died in the first month after EVAR procedure including 2 ruptured AAA cases. So, this may be one of the reasons for boosting the overall rate of ARM. Also, as the limitations of this study, the relatively small sample size and short follow-up duration made contributions to this. A larger sample size for longer follow-up duration may provide different rate of ARM.

In addition, although a relatively strong correlation was observed between the enlargement rate of aortic volume and DMAX, there was a worry that another 11 cases (50%) of

Table 4 Anatomic characteristics according to enlargement of DMAX and aortic volume.

Variables	All (N = 82)	DMAX			Aortic volume		
		Enlargement	No enlargement	P-value	Enlargement	No enlargement	P-value
		11 (13.41%)	71 (86.59%)		22 (26.83%)	60 (73.17%)	
	n (%) or Mean (SD)	n (%) or Mean (SD)	n (%) or Mean (SD)		n (%) or Mean (SD)	n (%) or Mean (SD)	
Non-adherence with IFU	65 (79.27)	9 (81.82)	56 (78.87)	1.00[a]	20 (90.91)	45 (75.00)	0.14[a]
Non-healthy proximal aortic neck	33 (40.24)	8 (72.73)	25 (35.21)	0.02[a]	16 (72.73)	17 (28.33)	<0.001[b]
Proximal aortic neck diameter (mm)	21.68 (2.78)	22.73 (2.00)	21.52 (2.85)	0.09[c]	21.36 (2.46)	21.80 (2.89)	0.67[c]
Angle $\alpha > 60°$	23 (28.05)	6 (54.55)	17 (23.94)	0.07[a]	11 (50.00)	12 (20.00)	<0.01[b]
Angle $\beta > 45°$	19 (23.17)	6 (54.55)	13 (18.31)	0.02[a]	9 (40.91)	10 (16.67)	0.02[b]
Proximal aortic neck length<15 mm	6 (7.32)	1 (9.09)	5 (7.04)	1.00[a]	3 (13.64)	3 (5.00)	0.34[a]
Calcium≥50%	6 (7.32)	2 (18.18)	4 (5.63)	0.18[a]	2 (9.09)	4 (6.67)	0.66[a]
Thrombus≥50%	1 (1.22)	0	1 (1.41)	1.00[a]	1 (4.55)	0	0.27[a]
Conical shape (proximal aortic neck)	12 (14.63)	3 (27.27)	9 (12.68)	0.20[a]	5 (22.73)	7 (11.67)	0.29[a]
Aortic bifurcation diameter<18 mm	6 (7.32)	0	6 (8.45)	1.00[a]	2 (9.09)	4 (6.67)	0.66[a]
Complex iliac artery	57 (69.51)	7 (63.64)	50 (70.42)	0.73[a]	16 (72.73)	41 (68.33)	0.70[b]
Rt iliac artery stenosis	5 (6.10)	1 (9.09)	4 (5.63)	0.52[a]	1 (4.55)	4 (6.67)	1.00[a]
Lt iliac artery stenosis	12 (14.63)	1 (9.09)	11 (15.49)	1.00[a]	4 (18.18)	8 (13.33)	0.73[a]
Rt Common iliac artery landing zone shortage	17 (20.73)	1 (9.09)	16 (22.54)	0.44[a]	4 (18.18)	13 (21.67)	1.00[a]
Lt Common iliac artery landing zone shortage	11 (13.41)	0	11 (15.49)	0.34[a]	2 (9.09)	9 (15.00)	0.72[a]
Rt Common femoral artery stenosis	2 (2.44)	1 (9.09)	1 (1.41)	0.25[a]	1 (4.55)	1 (1.67)	0.47[a]
Lt Common femoral artery stenosis	3 (3.66)	1 (9.09)	2 (2.82)	0.35[a]	2 (9.09)	1 (1.67)	0.17[a]

DMAX: maximal aortic diameter, IFU: instructions for use, α: infrarenal angulation, β: suprarenal angulation, Rt: right, Lt: left.

[a] P-value by fisher-exact test.
[b] P-value by chi square-test.
[c] P-value by wilcoxon rank-sum test.

aortic volume enlargement were not identified by the DMAX measurement during post-EVAR surveillance. Among these 11 patients, there were nine patients with endoleaks and two of them needed and underwent reintervention for endoleaks, including one ARM patient and three non-ARM patients. As other studies pointed out, aneurysm volume enlargement is not always reflected by similar changes of DMAX, and volume measurement was more sensitive to aneurysm enlargement than the DMAX measurement.[12,17] Van Keulen et al[18] indicated that the DMAX measurement would miss 50% or more of cases of aneurysm volume increase.

The volume measurement has several advantages over the DMAX measurement in evaluating aneurysm sac changes after EVAR. Geometrically, diameter only refers to a linear change of a planar graph; however, volumetric analysis may provide a more comprehensive measurement of the aneurysm after EVAR, as volume contains the summation of all the cross-sectional diameters of the aneurysm. Armon et al also pointed out that using diameter measurement to evaluate the three-dimensional object is a weakness in most other studies but that volumetric analysis will allow a more accurate assessment.[19] Volumetric analysis is a more sensitive option, detecting the aneurysm change earlier.[3] Any change in DMAX of an aneurysm is reflected by a volume change proportional to the cube of the diameter. Parr and colleagues proved that an enlargement of 1 mm in DMAX equal to 10 ml enlargement of volume within an aneurysm of 60 mm length.[17] In this study, we obtained similar results. Volume measurement is more reproducible and has less variability than DMAX measurement,[20] because the DMAX measurements could be influenced by many factors. Examples of these factors are the lying position of the patient within the CT scanner and the patient's blood pressure. The acquisition may varied between each follow-up scan.[3] In addition, the position of the DMAX may change with the morphologic changes in the aneurysm, and different thickness of CT slices may influence assessment. But volume measurement does not have the above deviations, because it always includes all target areas as three-dimensional. Thus, this measurement is operator independent.[20] As others[14] have stated, volume

Table 5 Procedure details according to enlargement of DMAX and aortic volume.

Variables	All (N = 82)	DMAX			Aortic volume		
		Enlargement	No enlargement	P-value	Enlargement	No enlargement	P-value
		11 (13.41%)	71 (86.59%)		22 (26.83%)	60 (73.17%)	
	n (%) or Mean (SD)	n (%) or Mean (SD)	n (%) or Mean (SD)		n (%) or Mean (SD)	n (%) or Mean (SD)	
Devices				0.94[a]			0.64[a]
Endurant	26 (31.71)	4 (36.36)	22 (30.99)		8 (36.36)	18 (30.00)	
Zenith	28 (34.15)	5 (45.45)	23 (32.39)		10 (45.45)	18 (30.00)	
Excluder	19 (23.17)	2 (18.18)	17 (23.94)		3 (13.64)	16 (26.67)	
VIABAHN	5 (6.10)	0	5 (7.04)		1 (4.55)	4 (6.67)	
Seal	3 (3.66)	0	3 (4.23)		0	3 (5.00)	
TAG	1 (1.22)	0	1 (1.41)		0	1 (1.67)	
Procedures				0.19[a]			0.15[b]
Conventional EVAR	33 (40.24)	2 (18.18)	31 (43.66)		6 (27.27)	27 (45.00)	
EVAR with adjunctive procedures	49 (59.76)	9 (81.82)	40 (56.34)		16 (72.73)	33 (55.00)	
Hospital stay (days)	14.87 (47.90)	7.18 (3.60)	16.06 (51.40)	0.57[c]	9.50 (7.20)	16.83 (55.83)	0.59[c]
Follow-up duration (months)	21.02 (17.59)	28.55 (14.94)	19.86 (17.78)	0.06[c]	23.91 (16.22)	19.97 (18.08)	0.26[c]

DMAX: maximal aortic diameter, EVAR: endovascular aneurysm repair.
[a] P-value by fisher-exact test.
[b] P-value by chi square-test.
[c] P-value by wilcoxon rank-sum test.

measurement of an aneurysm can be performed with non-contrast enhanced CT scans to evaluate the aneurysm sac changes after EVAR. This can reduce the use of contrast agents to avoid unnecessary renal problems,[21] can reduce the amount of radiation exposure,[14,22] and can significantly reduce the follow-up costs.[23] The contrast enhanced CT scans should be prescribed to patients with a volume enlargement of $\geq$12% on non-contrast enhanced CT scans.

Table 6 Outcomes according to enlargement of DMAX and aortic volume.

Variables	All (N = 82)	DMAX			Aortic volume		
		Enlargement	No enlargement	P-value	Enlargement	No enlargement	P-value
		11 (13.41%)	71 (86.59%)		22 (26.83%)	60 (73.17%)	
	n (%) or Mean (SD)	n (%) or Mean (SD)	n (%) or Mean (SD)		n (%) or Mean (SD)	n (%) or Mean (SD)	
Endoleak	30 (36.59)	11 (100)	19 (26.76)	<0.001[a]	20 (90.91)	10 (16.67)	<0.001[b]
Endoleak occurrence time				<0.001[a]			<0.001[a]
Initial endoleak	13 (15.85)	2 (18.18)	11 (15.49)		10 (45.45)	3 (5.00)	
Late endoleak	17 (20.73)	9 (81.82)	8 (11.27)		10 (45.45)	7 (11.67)	
Initial major endoleak	2 (2.44)	2 (18.18)	0	0.02[a]	2 (9.09)	0	0.07[a]
Late major endoleak	6 (7.32)	6 (54.55)	0	<0.001[a]	6 (27.27)	0	<0.001[a]
Endoleak treatment	9 (10.98)	5 (45.45)	4 (5.63)	<0.001[a]	7 (31.82)	2 (3.33)	<0.001[b]
Reintervention	19 (23.17)	6 (54.55)	13 (18.31)	0.02[a]	9 (40.91)	10 (16.67)	0.02[b]
Mortality				0.33[a]			1.00[a]
ARM	7 (8.5)	1 (100)	6 (30.00)		2 (40.00)	5 (31.25)	
Non ARM	14 (17.1)	0	14 (70.00)		3 (60.00)	11 (68.75)	

DMAX: maximal aortic diameter, ARM: aneurysm related mortality.
[a] P-value by fisher-exact test.
[b] P-value by chi square-test.

In addition, other researchers found that three dimensional ultrasound (3D-US) could provide good reproducibility, accurate image plane orientation and diameter estimation in measuring aneurysm volume.[24,25] 3D-US can also eliminate the inherent radiation exposure and contrast burden of the CT scan. Although it is unavailable to measure the aneurysm volume by ultrasound technology in clinical practice as yet, it has a potential complement in the AAA monitoring program.[26]

It was reported that advanced age was an independent risk factor for sac enlargement after EVAR, though the mechanisms are still unclear.[27] Another study[28] showed that undergoing EVAR with an age ≥80 years was a predictor of sac enlargement, which is consistent with the results of this study. Patients with advanced age may have larger aneurysms associated with longer-term growth of aneurysm sacs and more weakness of aneurysm walls, contributing to the enlargement of sac after EVAR.

In this study, patients with hyperlipidemia were more likely associated with no enlargement of the DMAX after EVAR. This could be presumed to be the effect of the statin, since all the patients with hyperlipidemia were treated with statin therapy. Others found that the statin therapy was effective on aneurysmal sac regression.[29,30] In this study, however, there was no indication of any relationship between the aortic volume changes and statin therapy. Patients in the aortic volume—enlargement group were more likely to have lower BMI than those in the no-enlargement group, which seems to be contrary to the opinion of other researchers.[31]

Proximal aortic neck angulation was associated with sac diameter enlargement. In particular, suprarenal aortic angulation non-adherence with IFU was a significant factor for the DMAX enlargement after EVAR in this study. There was lack of data on the DMAX enlargement in patients with suprarenal aortic angulation non-adherence with IFU. There as only limited data showing that infrarenal aortic neck angulation >60° was associated with aneurysm sac enlargement after EVAR,[28] but no difference was reported regarding sac enlargement in another study.[32] The proximal aortic neck angulation was associated with aortic volume enlargement. Suprarenal and infrarenal aortic neck angulation non-adherence with IFU were both significant factors for the aortic volume enlargement after EVAR in this study. This may be explained as the fact that an angulated proximal aortic neck could increase risk of type Ia endoleak,[33] which crated continuous pressurization of the aneurysm sac, which led to an enlargement of the aneurysm sac.

There were several limitations of this study. First, this was a non-randomized, retrospective study of a single center. Second, there was a relatively small number of cases and short follow-up durations. Third, un-unified image data (non-contrast or contrast enhanced CT scans or MRA) and slice thickness (range 2—5 mm) may affect the results. A larger sample size in a randomized, prospective study of a multicenter for longer follow-up duration may provide different results.

5. Conclusions

Volumetric analysis can predict successful endoluminal exclusion of AAAs more accurately than diameter measurement. A ≥12% increase in aortic volume was equivalent to a ≥5 mm increase in aortic diameter. Volumetric analysis after EVAR can be considered for accurate surveillance.

Conflicts of interest

There are no conflicts of interest to declare.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.asjsur.2018.12.006.

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