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Original Article

Changes in Neck Angle, Neck Length, Maximum Diameter, Maximum Area and Thrombus after Endovascular Aneurysm Repair

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Purpose: The correlation of initial anatomy of the aneurysm, aneurysmal remodeling and endoleaks is controversial. We performed a retrospective study to measure aneurysmal remodeling with time, and to assess the structural changes in the aneurysm neck after endovascular aneurysm repair (EVAR).
Materials and Methods: From January 2013 to February 2018, 108 patients with abdominal aortic aneurysms (AAA) underwent EVAR. Follow-up computed tomography images were available for 90 patients. Anatomic variables, including the neck angle, neck length, maximal diameter, maximal area, and thrombus volume were measured. Temporal changes were measured preoperatively, immediate postoperatively (within 1 week after EVAR), and at 6 months, 1 year, and 2 years post-EVAR. Correlation between the variables according to the temporal changes and presence of type Ia endoleaks (T1aE) was analyzed.
Results: The mean follow-up period was 10.63±20.34 months. Significant decreases in neck angle and length occurred immediately postoperative ($P<0.001$ and 0.036). Maximum diameter decreased at 6 months post-EVAR ($P=0.003$), but no significant changes in the maximal area occurred over time ($P=0.142$). Thrombus volume in the aneurysm sac increased immediately post-EVAR ($P=0.008$). There was no significant relationship between T1aE and neck changes in the group and time comparison ($P=0.815$ and 0.970).
Conclusion: Changes in neck angle, length and thrombus volume occurred immediately after EVAR, whereas a change in the maximum diameter of the AAA was noted 6 months after EVAR. Preoperative anatomic variables related with T1aE were not found.

Key Words: Abdominal aortic aneurysm, Endovascular procedures, Vascular remodeling, Endoleak

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INTRODUCTION

Endovascular aneurysm repair (EVAR) has advantages in short-term mortality and complications compared with open aneurysm repair (OAR) [1]. EVAR is being performed increasingly worldwide and it is used in the treatment of more than half of all abdominal aortic aneurysms (AAA) owing to its lesser invasiveness and the low risks of procedural complications [2,3]. However, according to a recent systematic review and meta-analysis, EVAR has higher long-term all-cause mortality, reintervention, and secondary rupture rates than OAR [4]. Recently, some reported that late complications such as endoleaks, graft migration, and sac expansion were likely correlated with the aneurysmal morphology after EVAR, especially with neck anatomy [5-9]. Others reported that sac size changes after successful EVAR could predict long-term outcomes and endoleaks [10-12].

Most previous studies addressed a single parameter of anatomic change without evaluating complex structural changes and mutual correlations. Therefore we investigated temporal changes in the aneurysm neck angle, neck length, maximal diameter, maximal area, and thrombus volume after successful EVAR. Mutual correlations of these factors, and the correlation between neck changes and type Ia endoleaks (T1aE) were also analyzed.

MATERIALS AND METHODS

1) Study population

The study protocol was approved by the Institutional Review Board of Daegu Catholic University Hospital (IRB no. CR-19-008). This study was exempted from the requirement of written informed consent owing to its retrospective nature based on medical records. From January 2013 to February 2018, 108 patients with AAA underwent EVAR in our institution. Computed tomography (CT) evaluation was performed preoperatively, immediately postoperatively (within 1 week), and at 6 months, 1 year, and 2 years after EVAR. Among them, 18 patients were excluded due to the lack of follow-up CT. Ninety patients, who had at least one post-EVAR CT, were included in this study. Follow-up CT images were available in 64 patients at 6 months, in 49 at 12 months, and in 23 at 24 months after EVAR. Aneurysm morphology, including neck angle, neck length, maximum diameter, maximum area, and thrombus volume of AAA, were evaluated, and analyzed according to time and correlation with each other.

2) Surgical procedure

All EVARs were performed under general or epidural anesthesia in an operating room equipped with a portable fluoroscopy unit (GE-OEC 9900; GE Healthcare, Salt Lake City, UT, USA). Bilateral cut-down of the common or superficial femoral artery was performed in all cases. We used a Zenith device (Cook Medical, Bloomington, IN, USA) in all but 10 cases; in these cases, we used Endurant Aorto-Uni-Iliac devices (Medtronic Endovascular, Santa Rosa, CA, USA) because the diameter was less than 17 mm at the aortic bifurcation.

3) Patient assessment

Three-dimensional CT angiography (3D CTA) was used to plan EVAR and check the aortoiliac anatomy. Measurements were performed on a TeraRecon workstation using Aquarius, iNtuition Ed, ver 4.4.6 (TeraRecon Inc., Foster City, CA, USA) with reformatting centerline and segmentating CTA data sets. The neck length, neck angulation, maximum diameter, maximum area, and thrombus volume

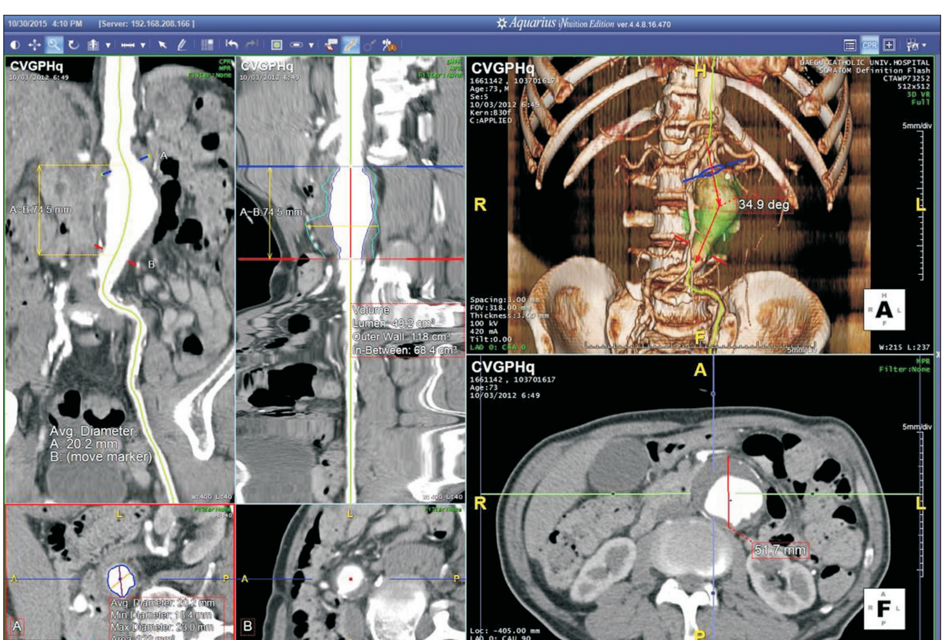

Fig. 1. Measurements of the anatomic variables are done using TeraRecon workstation. The center lumen line is automatically created (upper left). The curved aorta is straightened, and the infrarenal neck length and intraluminal thrombus was calculated (upper middle). Infrarenal neck angulation was measured by rotating the three-dimensional image (upper right). Maximum aortic diameter (lower right) and maximum area (lower left) were measured in orthogonal planes at the greatest point of aneurysm sac.

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were measured. The center lumen line was automatically created on the TeraRecon workstation and the curved aorta was straightened. The neck length was measured from the lower renal artery to the aneurysmal sac. The neck angulation between the infrarenal neck and the aneurysm sac was measured by rotating the 3D image. Aortic diameter and area were measured in the orthogonal planes at the widest region of the aneurysm sac. Thrombus volume was automatically obtained by subtracting the portion of the blood flow in the entire aneurysm sac along the central lumen line in a straightened view (Fig. 1). Follow-up 3D CTA was performed within 1 week, 6 months, and 1 year after EVAR and then annually.

4) Statistical analysis

Statistical analysis was performed using PASW Statistics 18.0 (SPSS Inc., Chicago, IL, USA). Continuous data are presented as means and standard errors. Categorical data are reported as numbers (percentages). Analysis of changes in the investigated parameters by time was performed using a generalized estimating equation (GEE) model. Analyses of changes in the investigated parameters by time, group, and interaction (time difference by group) were also performed using the GEE model. When we rejected the null hypothesis that all time points are equal, we performed a post-hoc (multiple comparison) analysis to check which time point was significantly different from the others. We expressed this result as 1>2,3,4,5 to indicate that it was the result of post-hoc analysis. Pearson correlation analysis was used to analyze the relationship between the change immediately after EVAR and the preoperative value. The change values were calculated as the preoperative value minus the immediate postoperative value. Pearson correlation analysis was used to analyze the pair-wise correlations among neck angle, neck length, maximum diameter, and maximum area. P-values <0.05 were considered statistically significant.

RESULTS

The median CT follow-up period was 10.63±20.34 months. On analyzing the structural changes over time after EVAR, neck angle and neck length decreased immediately after EVAR and no significant changes occurred thereafter. The maximum diameter showed a significant decrease at 6 months after EVAR, but the maximum area did not differ over time. The intraluminal AAA thrombus volume increased immediately after EVAR, but did not change significantly thereafter (Table 1).

We analyzed the correlations between the parameters in the immediate post-EVAR changes. We found that the larger the neck angle and the longer the neck length before EVAR, the more significant the decreases in neck angle and neck length immediately after EVAR. Additionally, we found that the larger the intraluminal thrombus volume before EVAR, the more significant the increase in thrombus volume immediately after EVAR. However, the maximum diameter and maximum area did not change immediately after EVAR (Table 2).

Hostile neck anatomy was defined as having a neck angle more than 60° and neck length less than 15 mm. The subdivision of each factor was used to investigate the dif-

Table 1. Analysis of temporal morphologic changes of abdominal aortic aneurysms after endovascular aneurysm repair during 24-month follow-up

Variable	Preoperative[1] (n=90)	1 week[2] (n=90)	6 months[3] (n=64)	12 months[4] (n=49)	24 months[5] (n=23)	P-value
Neck angle (degree)	49.232 (26.847±2.213)	30.934 (18.432±2.213)	31.677 (18.829±2.625)	30.245 (18.439±3.000)	28.411 (16.912±4.378)	<0.001[a] 1>2,3,4,5[b]
Neck length (mm)	36.914 (14.519±1.399)	31.381 (12.380±1.399)	31.198 (12.485±1.659)	32.419 (13.625±1.896)	32.491 (14.379±2.768)	0.036[a] 1>2,3,4,5[b]
Maximum diameter (mm)	54.026 (11.213±1.216)	54.071 (11.145±1.216)	51.586 (11.903±1.442)	47.314 (11.789±1.648)	48.139 (13.817±2.405)	0.003[a] 1,2>3,4,5[b]
Maximum area (cm^2)	24.335 (10.440±1.104)	25.284 (10.600±1.110)	24.079 (10.449±1.312)	20.728 (9.798±1.503)	22.014 (11.879±2.220)	0.142
Thrombus (cm^3)	80.984 (56.815±8.420)	121.159 (90.200±8.469)	115.578 (90.911±10.032)	93.347 (80.483±11.522)	94.457 (77.596±17.237)	0.008[a] 1<2,3,4,5[b]

Values are presented by mean (standard deviation±standard error). The P-values were calculated using generalized estimating equation model.

[a]Statistically significant with P<0.05. [b]Multiple comparison result by contrast.

ferences over time. AAA with a maximum diameter of 50 mm were indicated for surgery. We divided the patients into 2 groups according to the median values of maximal area and thrombus volume (20 cm^2 and 70 cm^3, respectively). No significant differences were found in either group compared with the changes over time according to the previous criteria (Table 3).

The correlations between the parameters were also examined. We found that the larger AAA diameter led to the development of the larger neck angle, shorter neck length, larger maximum area, and greater intraluminal thrombus volume (Table 4).

T1aE after EVAR was identified in 9 patients. When we analyzed the temporal changes in neck anatomy in subgroups with or without T1aE, we found no significant correlation between T1aE and neck changes by group and time (P=0.815 and 0.970) (Table 5). All T1aE were treated with additional procedures such as ballooning or stenting with a Palmaz balloon-expandable stent (Cordis, Miami Lakes, FL, USA).

Table 2. Correlation analysis of preoperative variables to changes immediately after endovascular aneurysm repair

	γ	P-value
Neck angle	0.749	<0.001[a]
Neck length	0.540	<0.001[a]
Maximum diameter	0.129	0.226
Maximum area	0.016	0.882
Thrombus volume	–0.318	0.003[a]

The P-values were calculated using Pearson correlation analysis.
[a]Statistically significant with P<0.05.

DISCUSSION

EVAR is an important alternative to OAR for treating

Table 3. Analysis of temporal morphologic changes of abdominal aortic aneurysms after endovascular aneurysm repair in dichotomized variables

Variable		Pre-operative	Post-operative[1]	6 months[2]	12 months[3]	24 months[4]	P-value		
							T	G	T×G
Neck angle (degree)	≤60 (n=58)	32.443±2.000	27.837±1.654	28.954±1.957	28.371±2.211	28.411±3.161	0.645	<0.001[a]	0.993
	>60 (n=32)	78.230±2.632	74.283±6.189	72.525±7.580	74.300±10.719	73.824±23.026			
Neck length (mm)	≤15 (n=7)	13.457±1.100	12.045±3.015	11.243±3.780	11.063±3.780	8.550±5.000	0.760	<0.001[a]	0.861
	>15 (n=83)	38.893±1.190	34.073±1.125	33.649±1.325	35.979±1.543	37.532±2.294			
Max. diameter (mm)	≤50 (n=34)	46.628±0.998	46.804±1.040	43.462±1.256	40.716±1.372	41.633±2.206	<0.001[a]	<0.001[a]	0.624
	>50 (n=56)	65.122±1.222	64.972±1.274	62.719±1.471	58.678±1.801	55.236±2.304	1,2>3,4[b]		
Max. area (cm^2)	≤20 (n=41)	17.663±0.920	18.760±0.947	16.822±1.160	15.658±1.270	16.203±2.009	0.001[a]	<0.001[a]	0.432
	>20 (n=49)	34.630±1.143	35.645±1.193	33.755±1.339	29.177±1.640	28.988±2.200	1,2>3,4[b]		
Thrombus (cm^3)	≤70 (n=47)	47.818±8.296	79.086±9.313	65.486±11.675	60.217±12.610	61.933±19.939	<0.001[a]	<0.001[a]	0.445
	>70 (n=43)	136.261±10.711	193.472±12.21	180.511±13.293	151.812±16.752	137.822±23.023	1,2>3,4[b]		

Values are presented by mean±standard error. The P-values were calculated using generalized estimating equation model.
T, time; G, group; max, maximum.
[a]Statistically significant with P<0.05. [b]Multiple comparison result by contrast.

Table 4. Correlation analysis between the anatomical variables

		Neck angle	Neck length	Maximum diameter	Maximum area	Thrombus
Neck angle	γ	1.000	0.044	0.209	0.202	0.176
	P-value		0.447	<0.001[a]	<0.001[a]	0.002[a]
Neck length	γ		1.000	0.113	0.111	0.142
	P-value			0.048[a]	0.053	0.013[a]
Maximum diameter	γ			1.000	0.930	0.845
	P-value				<0.001[a]	<0.001[a]
Maximum area	γ				1.000	0.847
	P-value					<0.001[a]

The P-values were calculated using partial correlation analysis.
[a]Statistically significant with P<0.05.

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Table 5. Correlation of the type 1a endoleaks with the neck anatomic variables

Variable	Group		Pre-operative[1]	Post-operative[2]	6 months[3]	12 months[4]	24 months[5]	P-value		
								T	G	T×G
Neck angle (degree)	Type Ia endoleak	No (n=81)	47.936±2.314	30.252±2.314	30.639±2.758	30.046±3.139	28.592±4.908	<0.001[a] 1>2,3,4,5[b]	0.121	0.815
		Yes (n=9)	60.889±6.941	37.067±6.941	40.129±7.870	32.000±9.312	27.760±9.312			
Neck length (mm)	Type Ia endoleak	No (n=81)	37.260±1.473	31.571±1.473	31.372±1.756	32.401±1.998	32.05±3.124	0.575	0.704	0.970
		Yes (n=9)	33.800±4.418	29.667±4.418	29.786±5.010	32.580±5.928	34.080±5.928			

Values are presented by mean±standard error. The P-values were calculated using generalized estimating equation model.
T, time; G, group.
[a]Statistically significant with P<0.05. [b]Multiple comparison result by contrast.

high-risk AAA with suitable anatomies [13,14]. However, EVAR has higher reintervention and secondary rupture rates than OAR over time [4]. This is related to the structural changes of AAA over time after EVAR. In our study, the neck angle, neck length, and thrombus volume changed immediately, and the diameter changed 6 months after EVAR.

The neck requires a sufficient sealing zone to prevent T1aE and stent graft migration after EVAR [15]. Neck anatomy is the most important factor in EVAR success, and manufacturers recommend EVAR in aneurysms with suitable neck anatomy, defined as having a neck angle less than 60° and neck length more than 15 mm. Many researchers reported the disadvantages and poor outcomes of EVAR in the treatment of aneurysms with hostile neck anatomy that did not meet the criteria [16-18]. The neck angle decreased significantly within 1 week after EVAR and then gradually decreased thereafter [6,7,19]. When the preoperative neck angle was greater than 60°, it decreased immediately after EVAR [19]. In our study, there was a significant decrease in the neck angle immediately after EVAR, similar to those in previous studies. The greater the preoperative neck angle, the more the decrease in the neck angle immediately after EVAR. There was no significant difference over time between the two groups based on a neck angle cutoff value of 60°

Neck length also significantly reduced immediately after EVAR, and a longer neck length before EVAR resulted in a more significant decrease after EVAR. The neck length was dichotomized with a 15-mm cutoff, and there was no intergroup difference over time in our study. Changes in the neck length after EVAR were rarely studied owing to measurement difficulty. Instead of neck length, several studies focused on the change in neck diameter over time after EVAR. The neck diameter increased in most patients (86.0%) after EVAR, but sac expansion was not related with neck diameter [5]. The degree of neck dilatation was correlated with the degree of endograft oversizing but not with the device type [5,20].

The preoperative intraluminal thrombus volume of AAA plays a role in reducing type II endoleaks and increasing sac shrinkage after EVAR [21-23]. Our study showed a significant increase in the thrombus volume immediately after EVAR; the larger the thrombus volume was before EVAR, the greater was its increase after EVAR.

The sac shrinkage after EVAR seemed to occur later in most patients [24,25]. The reported sac shrinkage rates ranged from 18.6% to 44.5% [5,6,10,11]. Tsilimparis et al. [26] reported that the reduction of the aneurysm sac occurs at 1 to 12 months, and more obviously during the first 6 months. Our study also demonstrated a significantly decreased maximal diameter at 6 months after EVAR but a maximal area that did not differ significantly over time. Nowicka et al. [11] also concluded that the aneurysm cross-sectional area is determined by initial area size rather than time.

In our study, the correlations among factors showed that a larger diameter was related to a larger neck angle, shorter length, and larger thrombus volume. As a result, if the diameter increases, the aneurysm will have a hostile neck anatomy. It is advantageous to perform EVAR before the aneurysm sac becomes too large because of the difficulty in performing EVAR and the increased risk of associated procedural complications. In other words, because a larger AAA has a hostile neck anatomy, it may be better to treat it before the diameter increases.

Our study has several limitations. First, it was retrospective in nature. Second, it included a relatively small sample size of patients treated at a single center. Third, it had a limited ability to determine the exact timing of the changes owing to the long interval between the immediate postoperative time (within 1 week after EVAR) and 6 months after EVAR.

CONCLUSION

The neck angle and length of AAA significantly decreased and thrombus volume significantly increased immediately after EVAR. The maximum diameter of the AAA decreased 6 months after EVAR, and no statistically significant changes occurred thereafter.

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CONFLICTS OF INTEREST

The authors have nothing to disclose.

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AUTHOR CONTRIBUTIONS

Concept and design: JHL. Analysis and interpretation: JHL. Data collection: JHL. Writing the article: JHL. Critical, revision of the article: JHL. Final approval of the article: JHL. Statistical analysis: SGK. Obtained funding: JHL. Overall responsibility: KHP.

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