



Incidence and Risk Factors for Sac Expansion after Endovascular Aneurysm Repair of Abdominal Aortic Aneurysms

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Purpose: This study aimed to examine the sac changes after endovascular aneurysm repair (EVAR) in patients with abdominal aortic aneurysms.

Materials and Methods: We examined the aneurysm sac size initially and regularly after surgery in 157 consecutive patients who underwent EVAR in 2009-2019. Contrast-enhanced computed tomography (CT) scans were used as well as ultrasound images with non-enhanced CT scans in the patients with renal insufficiency. Sac expansion (SE) at 3 years was divided into two categories: progressive SE (PSE) defined as continuous sac enlargement of ≥ 5 mm on serial follow-up images at 1 and 3 years compared with the initial sac and delayed SE (DSE) defined as re-expansion of ≥ 5 mm compared with the regressed or stable sac at 1 year. The SE rate at 1 and 3 years and the risk factors for SE at 3 years were analyzed using logistic regression.

Results: During a median follow-up of 32.5 months, nine reinterventions in six patients were performed with open conversion ($n=5$) and endovascular repair ($n=4$). At 1 year, 112 patients underwent follow-up imaging. SE and sac regression were noted in 4 (3.6%) and 57 (50.9%) patients, respectively. Of the 64 patients with 3-year follow-up images, 16 (25%) exhibited SE (PSE [$n=6$] and DSE [$n=10$]). In the multivariable analysis, the risk factors for overall SE at 3 years were endoleaks at 1 year ($P=0.006$) and renal insufficiency ($P=0.003$).

Conclusion: During post-EVAR follow-up, patients with any endoleak at 1 year or renal insufficiency must be strictly monitored for SE development.

Key Words: Endovascular aneurysm repair (EVAR), Sac expansion, Risk factors, Renal insufficiency, Endoleak

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INTRODUCTION

Endovascular aneurysm repair (EVAR) is preferred as the first-choice treatment in fragile patients with abdominal aortic aneurysms (AAAs) requiring treatment. By 2010, the number of EVAR cases reportedly surpassed the number of open repairs in South Korea as well as in the USA [1,2].

However, the 15-year follow-up of EVAR trial 1 demonstrated that the early survival benefit of EVAR is canceled out by the inferior late survival, need for lifelong surveillance, and high rates of reintervention compared with open repair. Further, the increased late aneurysm-related mortality in the EVAR group is mainly attributable to secondary aneurysm sac rupture [3].

Sac shrinkage following EVAR is believed to be a surrogate marker of low occurrence of late complications or longer survival [4,5]; however, the incidence of sac expansion (SE) after EVAR is not negligible, and it is generally believed that SE above some degree should be corrected because of the possibility of rupture. The overall SE rate has been reported to be approximately 10% at 1 year and 40% at 5 years after EVAR, especially when the anatomy is unfit for instructions for use (IFU) [6,7].

Accordingly, many studies have been conducted regarding the factors influencing the sac changes after EVAR and the relationship between SE and consequences of reintervention or mortality. Many features of endoleaks, increasing age, hostile anatomy, and renal impairment have been presented as possible risk factors for SE after EVAR [7,8]. However, there seems to be a lack of robust data to support the factors that can anticipate SE in practice. This study aimed to investigate the sac changes at 1 and 3 years and to identify the predictive factors for SE at 3 years after EVAR.

MATERIALS AND METHODS

This study was approved by our Institutional Review Board (approval no. 2019-12-001), and given its retrospective design, patient informed consent was not required. Our study included 157 patients who underwent EVAR at a tertiary hospital in South Korea between October 2009 and February 2019. The patients were followed up for a median period of 32.5 (interquartile range, 11.9-55.6) months.

All consecutive patients with both intact and ruptured

AAAs sized ≥ 5 cm who underwent EVAR were enrolled. Patients who complained of aneurysm-related pain or had a saccular-shaped AAA and received EVAR were included in the study regardless of the aneurysm size. We targeted patients with preoperative and postoperative follow-up images; 112 had images from the first year, while 64 had images from both the first and third years after EVAR. Conversely, patients who received EVAR for iliac artery aneurysms sized ≥ 3.5 cm with or without small AAAs (< 5 cm) were excluded.

We used the AquariusNET software (TeraRecon Inc., San Mateo, CA, USA) and processed three-dimensional computed tomography (CT) images. The sac diameter, neck length, proximal and distal neck diameters, neck shape, suprarenal and infrarenal angles, distal aortic diameter, and iliac tortuosity were examined in planning EVAR. The aneurysm sac size was individually measured by two vascular surgeons based on a contrast-enhanced CT scan or ultrasound image with a non-enhanced CT scan in the patients with renal impairment. Considering the compatibility with ultrasound, the anteroposterior diameter was preferentially gauged.

The presence of endoleaks was determined by the attending physicians based on CT angiography or ultrasound images examined by registered vascular technologists. When the patients with renal insufficiency needed frequent follow-up because of SE or suspected endoleaks, contrast-enhanced ultrasound (CEUS) was preferred.

As outcomes of interest, we primarily analyzed the size of the aneurysm sac before and at 1 and 3 years after EVAR, suspected cause of SE, and risk factors for overall SE during the follow-up period. The characteristics of the patients and aneurysms and aneurysm-related deaths were

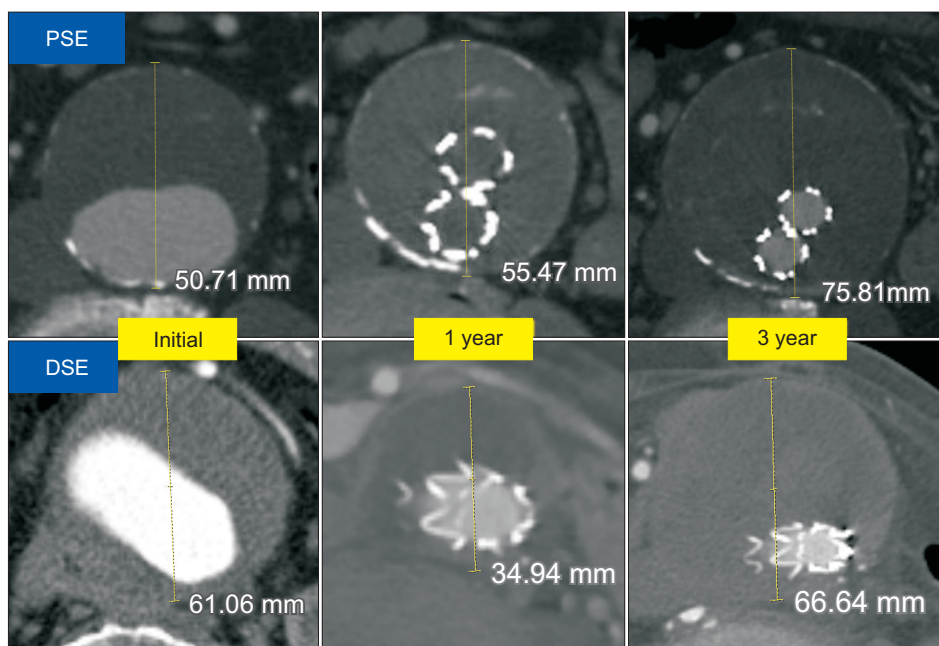


Fig. 1. Examples of progressive sac expansion (PSE) and delayed sac expansion (DSE). PSE group was defined as continuous sac enlargement of ≥ 5 mm on serial follow-up images and DSE group as re-expansion of aneurysm sac diameter of ≥ 5 mm at 3 years compared with the regressed or unchanged aneurysm sac at 1-year image. It was determined whether it had increased or not compared to the previous image, not the initial one.

also investigated.

We divided the patients with SE at 3 years into two groups: the progressive SE (PSE) group defined as exhibiting continuous sac enlargement of ≥ 5 mm on serial follow-up images at 1 and 3 years and the delayed SE (DSE) group defined as presenting re-expansion of the aneurysm sac diameter of ≥ 5 mm at 3 years compared with the regressed or unchanged aneurysm sac at the 1-year follow-up (Fig. 1). Notably, it was determined whether the size had increased compared with the previous image, not the initial image. The sum of the PSE and DSE groups was considered as the total SE (TSE) group.

1) Definitions

Renal insufficiency was defined as moderate to severe reduction in the estimated glomerular filtration rate (eGFR, < 60 mL/min/1.73 m², stages 3-5).

After completion of endograft placement and before removal of the delivery system, a completion angiogram was performed. Despite various additional procedures to eliminate type I or III endoleaks, the condition was recorded as a final endoleak when any suspicious type I or III leakage of contrast medium through the endograft was found.

Overall EVAR suitability was defined when both iliac and standard neck suitabilities were met. A standard (extended) neck IFU was defined as follows: aortic neck length, ≥ 15 (10) mm; suprarenal angle, $\leq 45^\circ$; infrarenal angle, $\leq 60^\circ$ (75); and neck diameter, 18 to 32 mm. When an unfavorable aortic neck anatomy, including a short neck, large angulation, and small or large neck diameters, outside each IFU was checked, the patients were categorized into the non-IFU group.

2) Operation details

When a direct approach to the aneurysm sac was required, we performed laparotomy, approached the retroperitoneal space, and dissected the proximal and distal aorta. Aortotomy was followed by ligation of branches, such as the lumbar artery or inferior mesenteric artery (IMA), omentopexy, or repair of the stent graft. A series of these processes is referred to as “open conversion”.

Regarding bleeding through the impaired endograft, we repaired the fabric defect using 6-0 prolene sutures. In this case, we used the expression “suture of the stent graft”.

When a type V endoleak (endotension) was identified as the cause of SE and no other leakage or endoprosthesis-related infection was found, we wrapped the exposed stent graft within the aneurysmal sac with the omentum. The omentum was fixed along the edge of the aneurysmal sac

using 3-0 silk sutures. This procedure is called “omentopexy”.

3) Follow-up protocols

The patients were scheduled to visit the outpatient clinic after discharge at 1, 6, and 12 months after EVAR and every year thereafter. Contrast-enhanced CT scans were obtained at 1 month and every year after EVAR. In the patients without endoleaks at 1 month, a CT scan was obtained annually. In the patients with endoleaks at 1 month, an additional CT scan was obtained 6 months after EVAR. Taking contrast-induced nephropathy into account, non-enhanced CT scans for size measurement and duplex ultrasound images for endoleak evaluation were subsequently examined in the patients with renal impairment but not on dialysis. In the patients with SE, reintervention was considered when they complained of abdominal pain or discomfort or according to the physician's decision considering the patients' condition and sac size.

4) Statistical analysis

Baseline characteristics, such as age, sex, comorbid conditions, smoking history, and aneurysm characteristics, were included as independent variables. The results were analyzed using IBM SPSS statistics (ver. 20.0; IBM Corp., Armonk, NY, USA). Numeric data with normal distribution were compared using Student t-test and presented as means and standard deviations; categorical variables were compared using the chi-squared test (for adequate-sized samples) or Fisher's exact test (for smaller samples). Logistic regression analyses were performed to identify the factors associated with SE after EVAR, and odds ratios (ORs) with 95% confidence intervals (CIs) were determined. The factors found to be significant in the univariable analyses were included in the multivariable analyses. Statistical significance for all tests was set at P-values of < 0.05 .

RESULTS

1) Patient characteristics

The patient demographics are detailed in Table 1. EVAR was conducted in 157 patients, of whom 129 (82.2%) were male; the mean age was 73 years. Coronary artery disease (CAD) and cerebrovascular disease (CVD) were found in 57 (36.3%) and 21 (13.4%) patients, respectively. Twenty-nine percent of the patients were preoperatively diagnosed with renal insufficiency. More than half of the patients had a history of smoking. There were no obvious differences in

the clinical features among all patients, patients with 1-year follow-up images, and patients with 1- and 3-year follow-up images.

2) Reintervention owing to sac expansion

During the median follow-up of 32.5 months, nine reinterventions in six patients were performed owing to SE (Table 2). Two patients underwent multiple reinterventions. In Patient 1, a type Ib endoleak was found at 15.7 and 20.3 months postoperatively, and two graft extensions were performed. Patient 2 underwent proximal extension under suspicion of a type Ia endoleak at approximately 4 years post-

operatively; however, the sac continually expanded, and the patient underwent open conversion and suture of the stent graft owing to a type III endoleak 6 months later. A month later, he received proximal extension again because of a type Ia endoleak causing 10-mm SE. In Patient 3, the cause of SE was considered a type II endoleak at 37.6 months after EVAR, and lumbar artery ligation was performed. The other three patients underwent open conversion because of SE. Patient 4 with type Ib endoleak ensuing 15-mm SE and aneurysm rupture after 40 months underwent hematoma evacuation, end-to-end anastomosis from the left limb to the left common iliac artery, and omentopexy. Since the bleeding site was clear, the endograft was not explanted.

Table 1. Characteristics of patients

At the time of EVAR	Total (n=157)	1 year follow-up (n=112)	3 year follow-up (n=64)
Age (y)	72.9±6.9	72.5±6.9	71.2±7.2
Sex, male	129 (82.2)	92 (82.1)	53 (82.8)
Comorbidities			
Hypertension	111 (70.7)	78 (69.6)	44 (68.8)
Diabetes mellitus	18 (11.5)	8 (7.1)	7 (10.9)
CAD	57 (36.3)	42 (37.5)	22 (34.4)
CHF	16 (10.2)	10 (8.9)	5 (7.8)
Arrhythmia	41 (26.1)	31 (27.7)	14 (21.9)
CVD	21 (13.4)	16 (14.3)	9 (14.1)
COPD	37 (23.6)	22 (19.6)	8 (12.5)
Renal insufficiency	46 (29.3)	30 (26.8)	15 (23.4)
Dyslipidemia	82 (52.2)	56 (50.0)	24 (37.5)
Smoking history	92 (58.6)	65 (58.0)	34 (53.1)
Malignancy	24 (15.3)	16 (14.3)	6 (9.4)
Antithrombotics ^a	130 (82.8)	98 (87.5)	55 (85.9)

Values are presented as mean±standard deviation or number (%).

EVAR, endovascular aneurysm repair; CAD, coronary artery disease; CHF, congestive heart failure; CVD, cerebrovascular disease; COPD, chronic obstructive pulmonary disease.

^aAntithrombotics indicate the incidence of patients who had taken an antiplatelet agent or anticoagulant, irrespective of the number of medications postoperatively.

Table 2. Reinterventions due to sac expansion during follow-up

Patient	Possible cause type	Initial sac size (mm)	Δ Sac size (mm)	Interval (mo)	Method	Procedure
1	Ib	63.4	9.1	15.7	Endo	Graft extension
	Ib		9.0	20.3	Endo	Graft extension
2	Ia	52.5	25.7	47.4	Endo	Proximal extension
	III		32.9	53.2	OC	Suture of graft
	Ia		42.2	54.2	Endo	Proximal extension
3	II	54.4	18.3	37.6	OC	Ligation, LA
4	Ib	53.1	15.4	40.4	OC	Anastomosis, E-E, left limb to left CIA, omentopexy
5	II	57.1	5.3	1.8	OC	Ligation, LA, IMA
6	V	53.7	8.3	6.9	OC	Omentopexy

Endo, endovascular reintervention; OC, open conversion; LA, lumbar artery; E-E, end to end; CIA, common iliac artery; IMA, inferior mesenteric artery.

Two other patients underwent ligation of the lumbar artery and IMA for a type II endoleak (Patient 5) and omentopexy for a type V endoleak (Patient 6).

3) Aneurysm-related death

During the follow-up period, two aneurysm-related deaths occurred. While surveillance of constant sac size, 6-mm SE without definite endoleak was observed at 49 months after EVAR. After 1 month, he was transferred to our emergency room (ER) with loss of consciousness due to excessive bleeding. CT confirmed a ruptured aneurysm due to a type Ib endoleak.

The other patient visited the ER with abdominal pain and high fever at 4 years after EVAR. Diagnosed with a graft-related infection, the patient underwent removal of the infected graft and reconstruction with the femoral vein. However, on postoperative day 58, the patient died of hospital-acquired pneumonia.

4) Follow-up images at 1 and 3 years after endovascular aneurysm repair

One hundred and twelve patients with 1-year follow-up images and sixty-four patients with both 1- and 3-year

follow-up images after EVAR were investigated. In the patients with both 1- and 3-year follow-up images, endoleaks were observed in 14 patients at 1 year, all of whom showed type II endoleaks. Endoleaks were found in 13 patients at 3 years, including 12 type II endoleaks and 1 type Ia endoleak. At 1 year, SE of ≥ 5 mm was noted in four (3.6%) patients. Two of them underwent open conversions; one patient underwent suture ligation of the lumbar arteries because of a type II endoleak, and the other patient underwent omentopexy and proximal fixation for a type V endoleak. The other two patients were placed under continuous surveillance. Sac regression of ≥ 5 mm compared with the initial CT finding was found in 57 (50.9%) patients and a stable sac in 51 (45.5%) patients.

Three-year follow-up images were obtained in 64 patients and compared with 1-year follow-up images. Sixteen (25.0%) of these patients presented with TSE (PSE [n=6] and DSE [n=10]). Between the first and third years after EVAR, one patient underwent reintervention owing to SE caused by a type Ib endoleak. Forty-one patients had a stable sac. Sac regression compared with the 1-year follow-up image finding was observed in seven (10.9%) patients.

5) Risk factors for total sac expansion

The proportion of renal insufficiency was significantly higher in the TSE group (n=16) than in the non-TSE group (n=48) (50.0% vs. 14.6%, $P=0.005$). The proportion of congestive heart failure (CHF) tended to be higher in the TSE group than in the non-TSE group. Regarding antithrombotics, more patients in the non-TSE group took antiplatelet agents or anticoagulants than the TSE group. No significant differences were found in the other clinical factors between the two groups (Table 3).

The anatomic features are detailed in Table 4; therein, no significant difference was found between the two groups. Regarding standard neck IFU suitability, no differences were observed between them. The proportion of patients satisfying each respective neck or iliac suitability, as well as overall suitability, did not also differ. However, the proportion of patients who did not meet the extended neck suitability tended to be higher in the TSE group than in the non-TSE group. Additionally, whether the graft was made of polytetrafluoroethylene (PTFE) did not seem to affect the TSE. The proportion of final endoleaks at the time of surgery tended to be higher in the TSE group than in the non-TSE group (25.0% vs. 8.3%, $P=0.099$). Any endoleak at 1 year (50.0% vs. 12.5%, $P=0.004$) and 3 years (62.5% vs. 6.3%, $P<0.001$) after EVAR occurred more frequently in the TSE group than in the non-TSE group.

Table 3. Clinical risk factors for total sac enlargement at 3 years

Variable	TSE (n=16)	Non-TSE (n=48)	P-value
Age (y)	73.1 \pm 7.5	70.9 \pm 7.1	0.312
Sex, male	14 (87.5)	39 (81.3)	0.716
Comorbidities			
Hypertension	11 (68.8)	33 (68.8)	>0.999
Diabetes mellitus	2 (12.5)	5 (10.4)	>0.999
CAD	6 (37.5)	16 (33.3)	0.761
CHF	3 (18.8)	2 (4.2)	0.095
Arrhythmia	4 (25.0)	10 (20.8)	0.736
CVD	2 (12.5)	7 (14.6)	>0.999
COPD	1 (6.3)	7 (14.6)	0.667
RI (eGFR <60 mL/min/1.73 m ²)	8 (50.0)	7 (14.6)	0.005
Dyslipidemia	7 (43.8)	17 (35.4)	0.551
Smoking history	10 (62.5)	24 (50.0)	0.386
Malignancy	0 (0.0)	6 (12.5)	0.323
Antithrombotics	11 (68.8)	43 (89.6)	0.039

Values are presented as mean \pm standard deviation or number (%). TSE, total sac expansion; CAD, coronary artery disease; CHF, congestive heart failure; CVD, cerebrovascular disease; COPD, chronic obstructive pulmonary disease; RI, renal insufficiency; eGFR, estimated glomerular filtration rate.

Table 4. Anatomical risk factors for total sac enlargement at 3 years after EVAR

Variable	TSE (n=16)	Non-TSE (n=48)	P-value
Initial diameter (mm)	55.7±8.9	57.9±8.4	0.377
Contained rupture	1 (6.3)	2 (4.2)	>0.999
EVAR suitability	10 (62.5)	27 (56.3)	0.661
Neck suitability (standard)	11 (68.8)	36 (75.0)	0.745
Neck suitability (extended)	12 (75.0)	44 (91.7)	0.099
Neck length (mm)	30.5±10.5	33.5±9.5	0.286
Neck diameter, proximal	21.2±2.1	20.7±2.4	0.401
Neck diameter, distal	21.5±2.7	21.4±2.6	0.960
Neck angulation, suprarenal	25.6±24.7	27.4±20.4	0.782
Neck angulation, infrarenal	49.3±25.1	43.0±22.0	0.345
Conical neck	1 (6.3)	7 (14.6)	0.667
Aortic tortuosity	1.11±0.08	1.10±0.07	0.688
Iliac suitability	13 (81.3)	35 (72.9)	0.740
CIA length, right	37.6±14.3	42.0±19.4	0.406
CIA length, left	44.9±14.1	44.7±20.1	0.970
CIA aneurysm	0 (0.0)	3 (6.3)	0.567
PTFE graft	11 (68.8)	38 (79.2)	0.498
Final endoleak	4 (25.0)	4 (8.3)	0.099
Endoleak at 1-year	8 (50.0)	6 (12.5)	0.004
Endoleak at 3-year	10 (62.5)	3 (6.3)	<0.001

Values are presented as mean±standard deviation or number (%). EVAR, endovascular aneurysm repair; TSE, total sac expansion; CIA, common iliac artery; PTFE, polytetrafluoroethylene.

6) Multivariable analysis for the influencing factors of total sac expansion at 3 years

In the univariable analysis, renal insufficiency (OR: 6.53, 95% CI: 1.79-23.81, P=0.004) and the presence of an endoleak at 1 year (OR: 7.00, 95% CI: 1.91-25.71, P=0.003) were significantly associated with the TSE at 3 years after EVAR. Furthermore, the analysis demonstrated that CHF, extended neck suitability, and the intraoperative presence of a final endoleak were associated with the TSE; however, the difference was not significant (Table 5). Antithrombotics seemed to inversely affect the TSE (OR: 0.21, 95% CI: 0.047-0.89, P=0.035). However, in the multivariable analysis, only renal insufficiency (adjusted OR [aOR]: 16.85, 95% CI: 2.58-110.03, P=0.003) or an endoleak at 1 year (aOR: 13.64, 95% CI: 2.09-88.98, P=0.006; Table 5) was significantly associated with the TSE.

DISCUSSION

Despite its position as an attractive alternative to open repair, EVAR has constantly been associated with the issue of long-term durability and surveillance. Sac behavior after EVAR has been considered an indicator of success or failure. In this study, the sac changes at 1 and 3 years and risk factors for TSE at 3 years after EVAR were investigated; the incidence of SE at 1 year after EVAR was lower in our study than in a previous literature [6]. However, based on the 3-year follow-up results, considerable cases of delayed expansion occurred in the patients with no sac change or

Table 5. Multivariable analysis for influencing factors of total sac expansion at 3 years after EVAR

Variable	Univariable analysis		Multivariable analysis	
	OR (95% CI)	P-value	Adjusted OR (95% CI)	P-value
Age	1.06 (0.97-1.15)	0.217		
Sex, Female	0.62 (0.12-3.22)	0.569		
CAD	1.20 (0.37-3.89)	0.761		
CHF	5.31 (0.80-35.21)	0.084	1.73 (0.24-93.32)	0.307
RI (eGFR <60 mL/min/1.73 m ²)	6.53 (1.79-23.81)	0.004	16.85 (2.58-110.03)	0.003
CVD	0.84 (0.16-4.51)	0.836		
Dyslipidemia	1.42 (0.45-4.49)	0.552		
Smoking history	1.67 (0.52-5.31)	0.388		
Size (initial)	1.03 (0.97-1.10)	0.376		
PTFE	0.58 (0.16-2.05)	0.397		
Neck suitability (extended)	0.27 (0.06-1.25)	0.095		
Endoleak at 1 year	7.00 (1.91-25.71)	0.003	13.64 (2.09-88.98)	0.006
Final endoleak	3.91 (0.96-15.94)	0.057	3.25 (0.46-22.77)	0.236
Antithrombotics	0.21 (0.047-0.89)	0.035		

EVAR, endovascular aneurysm repair; OR, odds ratio; CI, confidence interval; CAD, coronary artery disease; CHF, congestive heart failure; RI, renal insufficiency; eGFR, estimated glomerular filtration rate; CVD, cerebrovascular disease; PTFE, polytetrafluoroethylene.

regression at 1 year after EVAR. Of the 16 patients with TSE, 10 (62.5%) showed a stable or regressed sac at 1 year. This result indicates that sac shrinkage or stabilization can be achieved in the early phase, within at least 1 year after EVAR; however, patients should be continuously monitored because of the non-negligible probability of DSE.

Several factors, including younger age, smoking, and anatomical characteristics, such as a larger aneurysm diameter, a long and small neck, a higher proportion of thrombus, and less neck calcification, have been reported to affect sac reduction, although severe neck angulation, patent aortic side branches and their persistent endoleaks, and renal impairment are considered causes of SE [8-11]. There are many reports on the association of persistent endoleaks or inappropriate anatomical features with SE [7,12-17].

In this study, we compared the 3-year follow-up images of 64 patients with their 1-year follow-up images, and 16 (25.0%) patients demonstrated SE over 5 mm. Among them, an endoleak was noted in 8 patients at 1 year and 10 patients at 3 years. The most suspected type of an endoleak was type II (n=7 at 1 year and n=9 at 3 years). The possibility of SE was higher in the patients with type I or III endoleaks than in the patients with type II endoleaks because of the large pressurizing effect of the direct flow from the aorta. In contrast, it is still controversial whether type II endoleaks are generally considered benign. Some investigators have argued that the overall all-cause and aneurysm-related mortalities are unaffected by the presence of a type II endoleak. According to them, patients who were simply observed for type II endoleak-associated sac growth had aneurysm-related outcomes similar to those of patients who underwent reintervention [18,19]. However, type II endoleaks were the main type observed in our patients with TSE at 3 years, and it can be estimated that an untreated type II endoleak causes an increase in the intrasac pressure and consequent SE, which in turn produces a crack between the device and aortic wall, other types of endoleaks, and resultant sac rupture at the end. According to one report, type I or III endoleaks were newly discovered at a delayed timepoint in approximately 20% of patients with type II endoleaks [18]. In fact, our data indicated that two of the nine patients with type II endoleaks accompanied with SE at 3 years received reintervention because of newly discovered type I endoleaks during follow-up. Given these results, the treatment of type II endoleaks at 1 year seems to be of considerable importance. Regarding the efficacy and safety of embolization into the sac or branch vessels, favorable results in preventing type II endoleaks or reintervention have been reported [20-25]. Therefore, embolization before or during EVAR can be considered for the prevention of type II endoleaks and their associated complications, especially

in patients with a high risk of endoleaks.

Age, sex, other vascular diseases (CAD or CVD), smoking, and dyslipidemia, which were previously deemed meaningful, appeared to be nonsignificant; however, this finding is rather unreliable because of the small number of patients included. However, considering the significant results of the multivariable analysis, if patients with renal insufficiency must undergo EVAR, special attention should be paid to SE. It is well known that patients with CKD have a poor prognosis after open repair for AAAs [26-28]. However, because of the life-threatening course of AAAs when untreated, patients and physicians have no choice but to proceed with treatment. Because of the vulnerability of patients, EVAR tends to be preferred over open repair, notwithstanding the possibility of future reintervention. Nonetheless, both choices must be individually determined for each patient.

In this study, the patients with renal insufficiency accounted for 29.3% of all patients. As an influencing factor for sac behavior, renal impairment has not been well investigated. Patients with renal impairment usually have other cardio-cerebrovascular diseases that require medication. Warfarin or antiplatelet agents are known to induce bleeding tendencies, and in patients taking these drugs, a high risk of endoleaks has been reported [29]. In our study, most patients (82.8%) were taking at least one antiplatelet or anticoagulant agent. Of the 16 patients with TSE, 11 received a single antithrombotic agent. Significantly more patients in the non-TSE group were prescribed antiplatelet agents than those in the TSE group. However, this should not be interpreted as a protective effect of the medication against SE. Antiplatelets are usually prescribed after EVAR. In several patients with definite endoleaks or suspicious findings on a completion angiogram, this medication was not prescribed. In fact, final endoleaks appeared to affect the prescription of antithrombotics (OR: 0.153, 95% CI: 0.032-0.732, P=0.019). Based on our study findings, it was difficult to estimate the impact of antithrombotics on SE.

Of the 16 patients in the TSE group, an endoleak was not detected in eight (50.0%) patients at 1 year and six (37.5%) patients at 3 years, which suggests the possibility of endotension. Intriguingly, half of these patients showed renal insufficiency at 1 year (n=4) and 3 years (n=3). Additionally, in 51 patients with both 1- and 3-year follow-up images and without any endoleak at 3 years, only renal insufficiency showed a significant association with the TSE (aOR: 7.783, 95% CI: 1.037-58.408, P=0.046) after adjusting for other factors. Neither medication (P=0.568) nor any endoleak at 1 year (P=0.420) was associated with the TSE. Extensive research is needed to determine whether endotension occurs more frequently in patients with renal insufficiency.

As for Patient 2, proximal extension could be performed twice without chimney or snorkel techniques because the patient had been diagnosed with CKD and started dialysis 2 years after EVAR. Regarding the treatment of type III endoleaks, suture of the stent graft was proven to be insufficient given the subsequent reintervention in a short period. Notably, replacing the entire graft with a new material would be more desirable to prevent endoleaks, especially if the landing zone is expected to be insufficient for extension of the stent graft.

According to this study, the graft material (PTFE) had no influence on the TSE (Table 4). Regarding the device brand, a total of seven kinds (Endurant [Medtronic Cardiovascular, Santa Rosa, CA, USA] [n=23], Endurant IIs [Medtronic Cardiovascular] [n=28], Excluder [WL Gore and Associates, Flagstaff, AZ, USA] [n=61], C3 [WL Gore and Associates] [n=24], InCraft [Cordis Corp., Bridgewater, NJ, USA] [n=3], AFX [Endologix, Irvine, CA, USA] [n=9], and Zenith Flex [Cook Medical, Bloomington, IN, USA] [n=9]) of stent grafts were used. The number of cases was too small to assess its association with SE. However, in 64 patients with both 1- and 3-year follow-up images, only four types of endografts were used, and there was no significant association found between the device brand and SE or any endoleak at 1 and 3 years. Similarly, when Excluder and C3 were classified as Gore and Endurant and Endurant IIs as Medtronic, no significant correlation was observed (Supplementary Table 1).

Our study has several limitations. Three-year follow-up images were not available for 45 patients owing to the short follow-up duration. Thirty-two patients died within 3 years after surgery; 14 were lost to follow-up; and only a limited number of follow-up images (1-year follow-up images in 71.3% of the patients and 3-year follow-up images in 40.8%) were available, which seemed to have decreased the statistical power. However, the patients without 1-year follow-up images had mostly undergone recent surgeries, and most patients who were not followed up had already died, which probably suggests our appropriate patient selection for EVAR. Furthermore, because most patients with CKD (73.9%) were classified under stage 3, it was difficult to evaluate the difference according to the extent of renal impairment. In addition, there was no consistency in the size or endoleak measurement tools among all patients. However, in the patients with renal insufficiency, non-enhanced CT scans were combined with ultrasound images for evaluation, and in most patients, the same modality was consistently applied for the 1- and 3-year evaluations. Our study included patients with ruptured AAAs. It may be argued that the clinical situation of EVAR for ruptured AAAs can be completely different from that of elective EVAR. However, comparative research of sac changes between

ruptured and intact AAAs after EVAR has rarely been performed. One recent study showed that there was no difference in the sac behavior between ruptured and intact AAAs treated with EVAR from postoperative 1 year [30]. Based on this finding, we included patients with ruptured AAAs to reflect real-world data. However, the number of ruptured AAAs (n=8) was too small to assess the interrelationship between rupture and any endoleak or SE. In addition, the preoperative patency of the aortic branch vessels was not investigated, and the eGFR during follow-up was not evaluated because the patients under ultrasound surveillance did not undergo blood tests. Lastly, 44.4% and 57.1% of the patients with an endoleak at 1 and 3 years received ultrasound surveillance, respectively, as well as 75.0% of the patients (n=12) in the TSE group. In practice, CEUS has often been used to detect endoleaks after EVAR because of its high sensitivity and no risk of nephrotoxicity or radiation exposure. However, it may be argued that a more ideal surveillance system should be developed.

CONCLUSION

A significant proportion of patients demonstrated DSE at the 3-year imaging follow-up compared with the 1-year imaging follow-up; therefore, strict monitoring and surveillance are important for patients with any endoleak at 1 year or renal insufficiency, as SE may occur even after initial sac shrinkage or stabilization.

CONFLICTS OF INTEREST

The authors have nothing to disclose.

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Conception and design: HKK, SH. Analysis and interpretation: DH, HKK. Data collection: DH, HKK. Writing the article: DH, HKK. Critical revision of the article: HKK, SH. Final approval of the article: all authors. Statistical analysis: DH, HKK. Obtained funding: none. Overall responsibility: HKK.

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