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Comparison between Onyx and coil embolization for persistent type 2 endoleaks after endovascular aneurysm repair

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Purpose: Type 2 endoleaks (T2EL) are the most common form of endoleaks after endovascular aneurysm repair (EVAR). Several studies on the feasibility of embolization using ethylene vinyl alcohol copolymer (Onyx, Medtronic) for T2EL have been reported. The purpose of this study was to compare coil and Onyx embolization for T2EL treatment after EVAR.
Methods: Between August 2005 and July 2022, 46 patients underwent endovascular embolization for treatment of T2EL (15 Onyx and 31 coils). The primary endpoint was endoleaks resolution or significant aneurysm sac growth of >5 mm in maximal diameter after T2EL embolization. In addition, periprocedural factors, reintervention, sac rupture, and survival analysis were assessed.
Results: The follow-up period after embolization was significantly shorter in the Onyx group (11.6 months *vs*. 34.7 months, P = 0.016), and there was no difference in aneurysm sac growth rate between both groups (20.0% *vs*. 51.6%; P = 0.472, log-rank test). However, cases with multiple endoleak origins tended to be treated with Onyx (P = 0.002). When applying Onyx, there was no significant difference in results between the transarterial and translumbar approaches.
Conclusion: There appears to be no significant difference in the results of Onyx and coil embolization for T2EL treatment, although it is difficult to evaluate effectiveness due to the small number of cases and short follow-up period. However, in cases of multiple origin endoleaks or when the transarterial approach is not feasible, the Onyx by translumbar approach may be a more effective method.
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Key Words: Abdominal aortic aneurysm, Embolization, Endoleak, Endovascular aneurysm repair, Onyx

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INTRODUCTION

Type 2 endoleaks (T2EL) are the most common form of endoleaks following endovascular aneurysm repair (EVAR), with a prevalence rate of 10%–20% [1,2]. T2EL is caused by retrograde flow into the aneurysmal sac from the patent aortic artery branch after EVAR. Inflow from the inferior mesenteric artery (IMA) and lumbar artery is common and occurs through the median sacral or accessory renal artery [3,4]. Approximately 60%–80% of T2ELs spontaneously resolve within 6 months after EVAR. However, if T2EL persists for more than 6 months, it is defined as persistent T2EL [5]. In the long term, the probability of rupture is approximately 1%, so the presence of T2EL alone is not sufficient evidence of intervention, and such cases usually require follow-up observation [6,7].

The Society for Vascular Surgery (SVS) and the European Society for Vascular Surgery (ESVS) guidelines recommend treatment if there is sac enlargement of 5–10 mm or more during follow-up [6]. The goal of T2EL treatment is to block the junction of the patent aortic artery branch and the aneurysm sac and to eliminate inflow into the sac. Treatment includes endovascular embolization or surgical branch ligation. An interventional procedure generally is considered first as a minimally invasive approach; however, endovascular embolization of T2EL has some technical considerations such as anatomic structure, number and diameter of inflow aortic branches, unidentified hidden feeder vessels, and multiple nidus-like vascular malformations. The important points of endovascular embolization are approach target vessels and materials to use for embolization.

Ethylene vinyl alcohol copolymer (Onyx, Medtronic) is a nonadhesive, liquid embolic agent approved by the U.S. Food and Drug Administration to treat intracranial arteriovenous malformations. Since the introduction of Onyx for treatment of endoleak after EVAR by Martin et al. [8] in 2001, embolization of T2EL has been performed using coil, plug, glue, and Onyx. Embolization using these materials shows variable success rates, but there have not been many studies comparing these materials [6]. The purpose of this study was to compare and analyze coil and Onyx embolization for T2EL treatment after EVAR and to verify the effectiveness of Onyx embolization.

METHODS

Ethics statement

This study was approved by the Institutional Review Board of Samsung Medical Center (No. 2022-08-055), and all patients provided informed consent before the procedure.

Patients and study design

Patient characteristics and clinical data were collected retrospectively from electronic medical records between August 2005 and July 2022. A total of 728 patients underwent EVAR by 4 vascular surgeons in the Department of Vascular Surgery of Samsung Medical Center. All patients were followed with examination including CT angiogram (CTA) at 1 and 6 months after EVAR and then every 12 months. Thoracoabdominal enhanced CTA was used as a standard imaging modality. Patients with chronic kidney disease with a creatinine-based estimated glomerular filtration rate of less than 60 mL/min/1.73 m^2 were evaluated by nonenhanced CT with abdominal duplex sonography. Images were read for the presence of endoleaks and sac diameter enlargement by a vascular surgeon and radiologist. If T2EL was found, CTA and abdominal duplex sonography were performed every 6 months. Treatment was considered if an aneurysmal sac diameter increase of 5 mm or more was confirmed in the follow-up. Endovascular or surgical treatment was planned with consideration of the patient's concomitant disease and life expectancy.

Of the reviewed patients, 171 (23.5%) were identified with persistent or new T2EL at 6 months after EVAR. Among the 171 patients, 119 were treated through observation, 43 through embolization, and 5 received open surgical repair conversion. In 3 patients, the procedure failed in relation to type 1 endoleak or there were 2 patients of loss to follow up. One additional intervention involved a procedure for new onset T1b endoleak in T2EL patients. Including 3 cases of T2EL that occurred after EVAR treatment in another hospital, we selected 46 patients who underwent T2EL target embolization. Among these patients, 15 were treated with Onyx embolization and 31 with coil embolization. There were 4 cases that underwent open surgery in which visible endoleaks without a change in sac size. Of these 4 cases, 2 were performed for abdominal pain of nonspecific origin and 2 were performed for differential diagnosis with type 3 endoleaks.

All procedures for T2EL embolization were performed by 3 interventional radiologists with fluoroscopic angiogram. The supine position, local anesthesia with sedative control, and a percutaneous femoral transarterial approach were used as standard methods. Embolization was performed through a 5-French (Fr) guiding catheter and microcatheter of the 6-Fr sheath system. If catheter selection of the endoleak artery branch through the percutaneous transarterial approach was not feasible, direct translumbar puncture of the aneurysm sac was planned for embolization. In this case, the procedure was performed in a hybrid suite using simultaneous CT-guided angiography and fluoroscopy. The translumbar approach was performed using an 18- or 16-gauge spinal needle in the prone position. Onyx and coil embolization were performed selectively at the discretion of interventional radiologists, and the items considered for selection were whether the T2EL origin vessel could be selected using a microcatheter and

whether the vessel had a diameter that could be blocked with coil embolization. The coil used for embolization was selected among Concerto (Medtronic), Nester (Cook Medical), and Interlock (Boston Scientific) depending on the diameter, length, and cavity volume of the target vessel. Onyx was mainly used for sealing the inside of the aneurysm sac and for selective blocking of the target branch vessel. Onyx 34L LES packaging with a 6-mL vial (Medtronic) was shaken mechanically at room temperature for 20 minutes before use. For Onyx delivery through a microcatheter, dead space control was performed using dimethyl sulfoxide [9]. After confirmation of the block of inflow to the aneurysmal sac through completion angiogram with digit subtraction angiography, the procedure was terminated. Embolization stability and sac size were assessed by imaging at 1, 6, and 12 months after T2EL embolization. If there were remnant or recurrent endoleaks, the next treatment was determined based on sac enlargement of 10 mm or more.

Patient demographics and periprocedural outcomes were collected and analyzed. History of coronary procedure was limited to percutaneous coronary intervention or coronary artery bypass grafting; simple cardiac angiography was not included. Each case was classified as lumbar, iliolumbar, or IMA as the endoleak origin. Multiple origin is the case of embolization of 2 or more target vessels. In addition, aneurysm sac filling with Onyx in cases with multiple inflow branch orifices was classified as multiple origin. Indication of invention was based on sac size enlargement less than 5–10 mm within an interval follow-up. Endoleak resolution was noted when the endoleak was no longer observed in follow-up imaging. Aneurysm-related deaths included mortality due to graft infection, rupture, and stent migration.

Endpoint

The primary endpoint was the resolution of endoleaks or significant aneurysm sac growth of maximum diameter >5 mm after T2EL embolization. [6] The secondary endpoints were sac rupture, reintervention, and death.

Statistical analysis

Categorical variables are presented as numbers and percentages, and continuous variables are presented as medians with interquartile range (IQRs). Between-group differences were calculated using a chi-square test, Fisher exact test, and the Mann-Whitney U-test. Additionally, for sac growth >5

Table 1. Patients' characteristics and previous EVAR details

Characteristic	Onyx group	Coil group	P-value
No. of patients	15	31	
Age (yr)	76.0 (68.5–79.5)	70.0 (66.5–77.0)	0.159
Mael sex	12 (80.0)	24 (77.4)	>0.999
Underlying disease			
Hypertension	11 (73.3)	25 (80.6)	0.706
Diabetes mellitus	1 (6.7)	7 (22.6)	0.243
Coronary procedure	2 (13.3)	6 (19.4)	>0.999
COPD	1 (6.7)	5 (16.1)	0.647
CKD[a]	0 (0)	2 (6.5)	>0.999
Ex- or current smoker	6 (40.0)	11 (35.5)	0.766
AAA initial diameter (mm)	53.7 (51.0–60.0)	52.7 (50.0–57.9)	0.508
Piece type			>0.999
Bifurcated	15 (100)	29 (93.5)	
Aorto-uni-iliac	0 (0)	2 (6.5)	
Ruptured AAA	0 (0)	0 (0)	
Stent graft type			0.023
Cook Zenith	1 (6.7)	10 (32.3)	
Medtronic Endurant	8 (53.3)	14 (45.2)	
Gore Excluder	1 (6.7)	5 (16.1)	
Gore C3	1 (6.7)	2 (6.5)	
Endologix AFX2	1 (6.7)	0 (0)	
Cordis Incraft	3 (20.0)	0 (0)	
Follow-up after EVAR (mo)	46.6 (35.8–68.7)	68.7 (42.3–111.2)	0.073

Values are presented as number only, median (interquartile range), or number (%).
EVAR, endovascular aneurysm repair; COPD, chronic obstructive pulmonary disease; CKD, chronic kidney disease; AAA, Abdominal aorta aneurysm.
Onyx: Medtronic.
[a]Creatinine of ≥2 mg/dL.

mm, which was the endpoint, a log-rank test was performed considering the difference in the follow-up period between the 2 groups. Sac growth >5 mm, reintervention-free rate, and overall survival rate were analyzed using the Kaplan-Meier method. The comparison of multiple logistic regression results was conducted by controlling the time point until the 12-month follow-up period in both groups. All statistical analyses were performed using IBM SPSS Statistics ver. 27.0 (IBM Corp.). A P-value of <0.05 was considered statistically significant.

Table 2. Comparison of periprocedural details between patients treated using Onyx (Medtronic) *vs*. coil embolization for T2EL after EVAR

Variable	Onyx group (n = 15)	Coil group (n = 31)	P-value
Time to EL treatment (mo)	35 (24.7–57.8)	30.1 (21.1,42.4)	0.405
Increase in aneurysm sac size (mm)	5.7 (3.1–13.0)	4.9 (1.4–8.0)	0.182
Sac size at EL treatment (mm)	62.3 (57.3–68.0)	58.7 (55.0–63.0)	0.218
EL origin			0.002
Lumbar or iliolumbar	10 (66.7)	21 (67.7)	
IMA	0 (0)	9 (29.0)	
Multiple origin	5 (33.3)	1 (3.2)	
Indication for intervention			0.342
Sac enlargement 5–10 mm	8 (53.3)	22 (71.0)	
Sac enlargement ≥10 mm	6 (40.0)	6 (19.4)	
Visible EL, no sac change	1 (6.7)	3 (9.7)	
Approach			0.078
Translumbar (direct)	4 (26.7)	2 (6.5)	
Transarterial	11 (73.3)	29 (93.5)	
Amount of Onyx (mL)	10.0 (8.5–11.5)	NA	NA

Values are presented as median (interquartile range) or number (%).
T2EL, type 2 EL; EL, endoleak; IMA, inferior mesenteric artery; NA, not applicable.

Table 3. Comparison of outcomes and complications between patients treated using Onyx (Medtronic) *vs*. coil embolization for T2EL after EVAR

Variable	Onyx (n = 15)	Coil (n = 31)	P-value
Follow-up after embolization (mo)	11.6 (7.5–17.7)	34.7 (8.7–54.9)	0.016
Sac size at follow-up (mm)	66.3 (59.2–74.9)	67.9 (56.0–72.3)	0.657
Endoleak resolved	5 (33.3)	12 (38.7)	0.723
Aneurysm sac growth >5 mm	3 (20.0)	16 (51.6)	0.041, 0.472[a]
Reintervention	2 (13.3)	12 (38.7)	0.099
Time to reintervention (mo)	16.8 (11.6–21.9)	19.3 (15.2–45.9)	0.465
Reintervention type			NA
Coil embolization	0 (0)	4 (12.9)	
Open conversion	2 (13.3)	6 (19.4)	
Coil + open conversion	0 (0)	2 (6.5)	
Open conversion	2 (13.3)	8 (25.8)	0.460
Time to open conversion (mo)	16.8 (11.6–21.9)	27.6 (14.8–45.9)	0.433
Mortality	1 (6.7)	8 (25.8)	0.235
Graft infection	0 (0)	1 (3.2)	
Rupture	0 (0)	1 (3.2)	
Stent migration, bleeding	0 (0)	1 (3.2)	
Reperfusion injury	0 (0)	1 (3.2)	
Cancer	1 (6.7)	1 (3.2)	
Unknown, follow-up loss	0 (0)	3 (9.7)	
Aneurysm-related death	0 (0)	3 (9.7)	0.541

T2EL, type 2 endoleak; EVAR, endovascular aneurysm repair; NA, not applicable.
Values are presented as median with interquartile range (IQR) or number (%).
[a]Analyzed by log-rank test.

RESULTS

Among the 46 patients who underwent embolization in this study, 15 were treated with Onyx embolization and 31 with coil embolization. There was no significant difference in perioperative factors, median age, sex, underlying disease, and initial AAA diameter between the 2 groups. There was a significant difference in the stent graft type used at the time of EVAR (P = 0.023). There was no difference in follow-up after EVAR between the 2 groups (Onyx, 46.6 *vs.* coil, 68.7 months; P = 0.073) (Table 1).

The procedural data for Onyx and coil embolization are listed in Table 2. There was no significant difference in the absolute value of sac size or the degree of enlargement during follow-up between the 2 groups. In endoleak origin, cases with multiple endoleak origins tended to be treated by Onyx (P = 0.002). The amount of Onyx was expressed as a median value. Detailed analysis by section was not possible due to the small number of cases. The amount of Onyx used was 4–19.5 mL, and the median value was 10 mL (IQR, 8.5–11.5).

We also examined T2EL embolization outcomes (Table 3). There were no significant differences in sac size at follow-up, endoleak resolution rate, reintervention rate, and time to reintervention. Aneurysm sac growth rate after embolization, the primary endpoint of this study, was significantly higher in the coil group (Onyx, 20.0% *vs.* coil, 51.6%; P = 0.041) in the chi-square test. However, since the introduction of Onyx was relatively late in the study period, there was a difference in the follow-up period after embolization between the 2 groups (Onyx, 11.6 months *vs.* coil, 34.7 months; P = 0.016). Therefore, in the additionally performed log-rank test, it was confirmed that there was no significant difference between the 2 groups (P = 0.472).

There was no difference in mortality rates between the 2 groups. We examined the disease-free rate and overall survival of patients classified according to embolization material and found no significant difference in sac growth of >5 mm rate (P = 0.472), reintervention rate (P = 0.840), and overall survival (P = 0.453) (Fig. 1).

We next examined the 15 patients who underwent Onyx

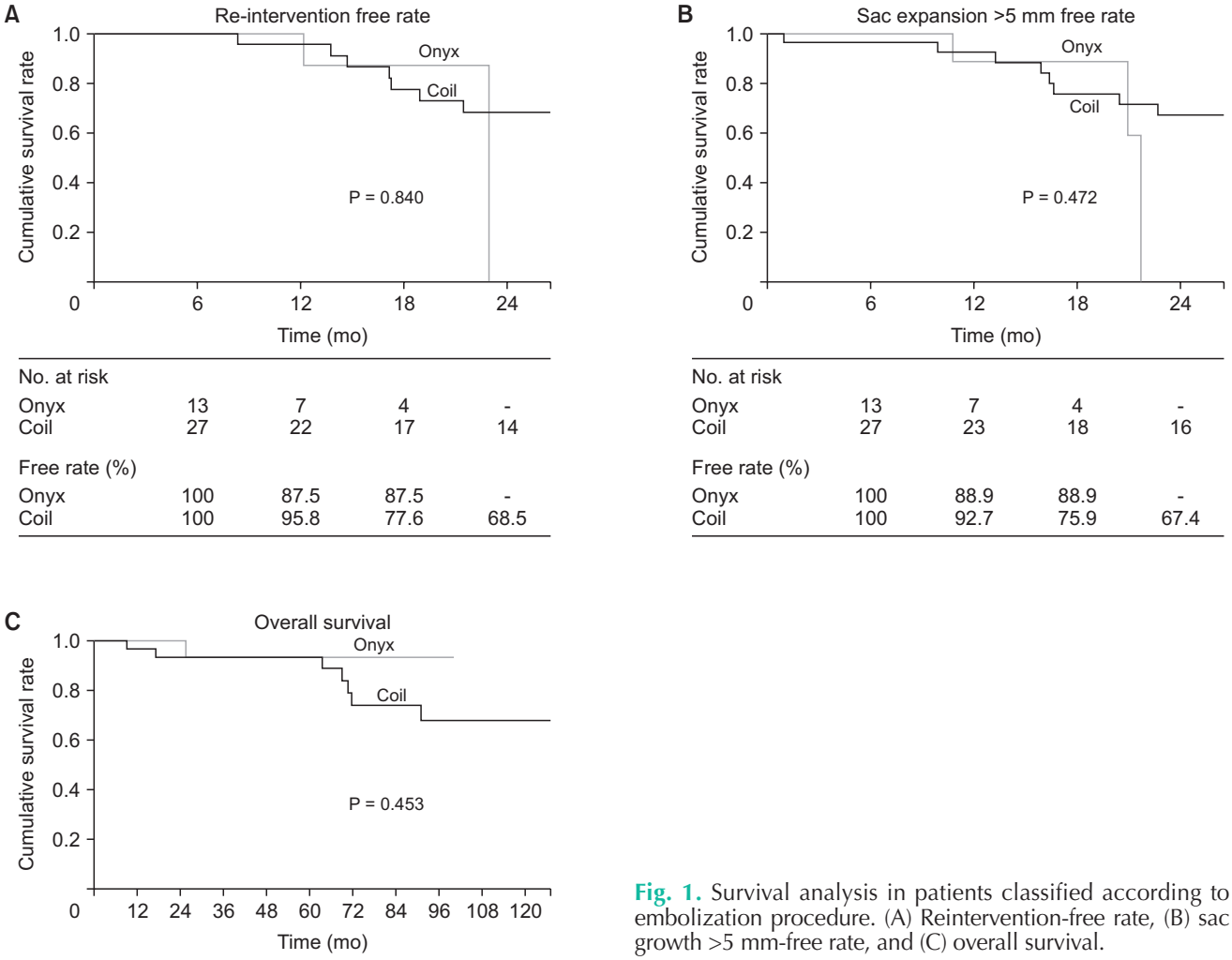

Fig. 1. Survival analysis in patients classified according to embolization procedure. (A) Reintervention-free rate, (B) sac growth >5 mm-free rate, and (C) overall survival.

Table 4. Comparison of outcomes between transarterial *vs*. translumbar approaches in patients treated using Onyx (Medtronic) embolization for T2EL after EVAR (n = 15)

Characteristic	Trans-A group	Trans-L group	P-value
No. of patients	11	4	
Age (yr)	78 (73.0–81.5)	69 (63.0–73.0)	0.067
Male sex	8 (72.7)	4 (100)	0.516
Coronary procedure	1 (9.1)	1 (25.0)	0.476
Ex- or current smoker	3 (27.3)	3 (75.0)	0.235
Sac size at EL treatment (mm)	60.2 (54.0–71.0)	65.6 (61.3–67)	0.571
Increase in diameter (mm)			0.097
<10	7 (63.6)	0 (0)	
≥10	4 (36.4)	2 (50.0)	
EL origin			0.560
Lumbar or iliolumbar	8 (72.7)	2 (50.0)	
Multiple	3 (27.3)	2 (50.0)	
Sac size at follow-up (mm)	69.0 (59.2–80.9)	66.3 (56.0–67.5)	0.497
EL resolved	3 (27.3)	2 (50.0)	0.560
Aneurysm sac growth >5 mm	3 (27.3)	0 (0)	0.516
Reintervention, OSR	2 (18.2)	0 (0)	>0.999
Aneurysm-related death	0 (0)	0 (0)	-

Values are presented as number only, median (interquartile range), or number (%).
T2EL, type 2 EL; EVAR, endovascular aneurysm repair; Trans-A, transarterial; Trans-L, direct translumbar puncture; EL, endoleak; IMA, inferior mesenteric artery; OSR, open surgical repair.

Table 5. Multiple logistic regression result between Onyx (Medtronic) *vs*. coil embolization

Variable	OR (95% CI)	P-value
Onyx	1.000 (reference)	0.016
Coil	11.134 (1.145–108.268)	
Variables of interest and adjustment		
Increase in diameter (mm)		
<5	1.000 (reference)	
≥5	0.369 (0.067–2.046)	0.254
≥10	10.235 (1.057–99.078)	0.045
Endoleak origin, lumbar artery	0.362 (0.060–2.187)	0.268

OR, odds ratio; CI, confidence interval.

embolization; periprocedural data and outcomes were compared between the transarterial and translumbar (direct puncture) approaches. There was no difference in endoleak origin or sac size at the time of endoleak treatment in the 2 approaches. This result is described in Table 4.

We analyzed the odds ratio for sac growth greater than 5 mm, which is the primary endpoint of this study. As shown in Table 5, increased size and endoleak origin were used as adjusted variables, and the confidence interval was rather wide because the sample size was small and not many variables showed a significant difference. The risk of sac growth in the coil group was higher than that of the Onyx group (P = 0.016). Multivariate analysis of reintervention did not yield any significant results.

DISCUSSION

This study focuses on T2EL embolization using Onyx. Although the number of cases is small (n = 15), the paper will be significant in that it is the first comparative study on Onyx embolization for T2EL treatment in Korea and there are actually not many comparative studies on Onyx and coil worldwide. By referring to recently published reports on the technical evaluation or outcome of Onyx embolization, it is possible to make some assumptions about the reasons for the good performance of Onyx embolization. First, given that access to various routes is possible, T2EL origin selection failure is relatively rare. This is not limited to comparison with coil embolization but may be a factor that can have a meaningful effect from the reintervention decision-making stage. Additionally, in the case of multiple origins, treatment by filling the sac cavity itself, rather than selecting and blocking inflow, has the effect of further reducing the possibility of outflow recanalization, which may also cause a low sac enlargement rate [8-10].

The SVS and ESVS guidelines recommend treating T2EL if there is aneurysm sac growth of 5–10 mm or more within the follow-up period, and various endovascular treatment options have been suggested [6]. However, a clear definition of successful intervention is lacking, and parameters for the technique, device, and material have not been established. The presence of T2EL can be confirmed during the initial EVAR procedure or T2EL, which was not visible during the initial

EVAR procedure, may be newly identified during the follow-up period. In general, the presence of T2EL is not an indication of treatment, as spontaneous resolution occurs in more than 60% of cases [11]. The SVS and ESVS guidelines recommend 6 months of follow-up for persistent T2EL; most cases show reduced or maintained sac size, and sac expansion occurs in approximately 25% of cases [12]. At 6 months after EVAR, the incidence of endoleak is approximately 10%–15%, and if it persists for more than 6 months, it is defined as persistent T2EL [13]. Since it is rare for sac expansion accompanied by T2EL to increase by more than 10 mm, and rupture due to sac expansion accompanied by T2EL is rare, additional treatment is recommended when a patient with persistent T2EL has sac expansion of 5–10 mm or more [14]. In our study, the sac expansion rate after intervention was 26% in patients with persistent T2EL (Onyx, 40.0% and coil, 19.3%), and the spontaneous resolve rate within the follow-up period was 36.9% (Onyx, 33.3% and coil, 38.7%). There was 1 case of rupture (2.1%) after coil embolization; this patient was lost to follow-up until reintervention, and reintervention was performed 16 months later due to aneurysmal sac rupture with 26-mm sac growth.

Ethylene vinyl alcohol copolymer (Onyx), introduced to treat cerebral arteriovenous malformations and dural fistulae [15], has specific intrinsic physical-chemical properties that allow embolization techniques that could not be considered with other embolic materials currently in use [16]. Onyx initially remains stable in liquid form in saturated solvent and is injected into vessels; when it contacts blood, the solvent is diluted, and the plastic polymer hardens to a solid form. Because it has nonadhesive properties, the technique for this agent is filling the vascular or aneurysm sac lumen, avoiding microcatheter obstruction during intervention and a weaker inflammatory effect on the vascular endothelium [9]. In T2EL situations, the aneurysmal sac generally contains 2 or more vascular paths, and these are often responsible for inflow and outflow roles, respectively. It often is technically difficult to embolize all these arterial paths with coil or glues. In this case, Onyx could provide a complete filling of the sac lumen with a liquid agent [17] (Fig. 2).

Endovascular embolization of T2EL does not require general anesthesia and is the preferred method prior to surgical treatment in terms of relatively safe minimally invasive treatment. Traditionally, IMA selection using a Riolan arch and marginal artery of Drummond through the superior mesenteric artery or coil embolization has been attempted by selecting the iliolumbar artery through the internal iliac artery. However, if the route to many potential vessels is long and anatomically difficult, the selection of the target vessel can be a technical

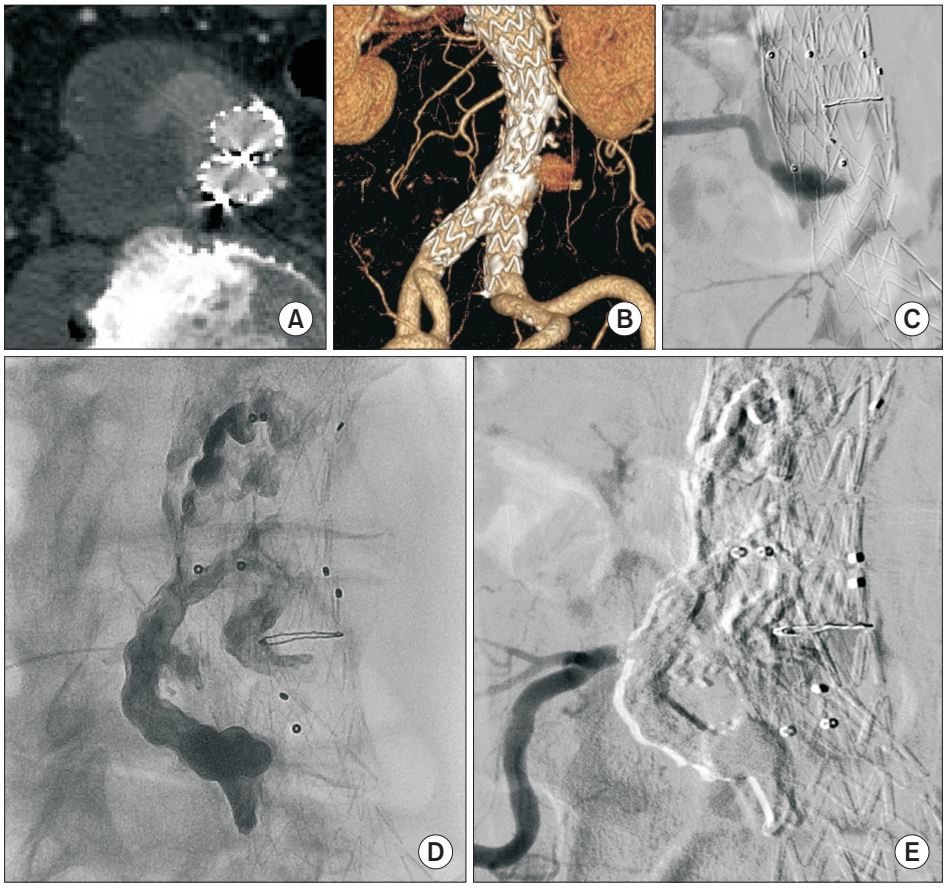

Fig. 2. Endoleak of uncertain origin, type 3 cannot be ruled out, treated by complete filling of the sac lumen using Onyx (Medtronic). (A) CT angiography, axial view; (B) CT angiography, 3-dimmensional reconstruction view; (C) diagnostic angiography; (D) Onyx application, and (E) post-procedural completion angiography.

challenge. To overcome this, various techniques have been used for endovascular and percutaneous embolization. Transarterial and direct sac puncture techniques have been used, and recently, alternative approaches including transcaval, transgraft, or perigraft were described [18-21]. Recent studies reported higher success and lower complication rates through the direct translumbar approach [7]. Through these technical advances, it is possible to shorten the interventional path length and facilitate the selection of target vessels.

Onyx is being used in peripheral interventional radiology; since Martin et al. [8] first used Onyx for T2EL treatment, studies on feasibility have been reported. Scallan et al. [10] stated that Onyx embolization was less likely to require reintervention than coil embolization (19% *vs*. 55%, $P < 0.01$). Although the technical preference of the operator may be reflected, in Scallan et al.'s study [10], the procedure was significantly biased toward direct translumbar puncture in Onyx embolization and transarterial approach in coil embolization. In our study, there was no difference in approach route and no significant difference in outcomes according to the approach route in the Onyx group (Table 4). Nuckles et al. [22] reported similar effectiveness compared to traditional coil and glue embolization. The method of measuring the volume and not the sac diameter was emphasized, but there were no significant points. And data on the technical approach were limited. Studies by Mozes et al. [23] and Ribé et al. [24], both Onyx embolization studies for T2EL, were based on large samples and long-term follow-up data, but they were not comparative studies. In Menges et al.'s study [25], even though transarterial Onyx embolization was technically useful, durability was low, with greater than 50% persistent or delayed T2EL. Vance et al. [26] reported the safety and effectiveness of the transabdominal and perigraft approach. Although this study also compared transarterial and translumbar approaches in Table 4, it was difficult to obtain statistical significance due to the small sample size. However, in cases of multiple origin endoleak or unfavorable transarterial approach, the trasnlumbar Onyx approach may be a more effective method. Long-term evaluation through many cases is necessary.

We analyzed the odds ratio for sac growth greater than 5 mm, which is the primary endpoint of this study because there was a significant difference between the 2 groups in the chi-square test (Onyx, 20.0% *vs*. coil, 51.6%; $P = 0.041$). As shown in Table 5, increased size and endoleak origin were used as adjusted variables. As adjusted variables, endoleak origin ($P = 0.002$), which showed a significant value in the previous comparison of Onyx and coil embolization, and increased size ($P = 0.097$), which showed a relatively significant P-value, were selected. Although a significant OR value was found at an increased size of >5 mm, in fact, this is thought to have a high possibility of bias. Since the sac size will increase depending on the follow-up period anyway, it is believed that the comparative risk of the Onyx group, which was recently introduced and has a short follow-up period for the patient group, will inevitably be measured as low. Additional long-term follow-up studies are needed.

There are some cost-benefit issues for the use of Onyx. First, the cost of Onyx is approximately $2,500 (US dollar) per 1 mL. In our study, 10 mL of Onyx was used, resulting in a cost of approximately $25,000 per procedure. In contrast, coils cost about $700–$1,100 based on an IMA or lumbar arterial endoleak with a size of 2–3 mm [27,28]. Additionally, safety information and amounts for Onyx embolization for endoleak have not been established. In previous studies and our current study, Onyx was used at approximately 4.9–13.4 mL [23,25]. Nuckles et al. [22] used 20 mL or more, and Namazi et al. [29] reported the safety of 30 mL Onyx.

This study has several limitations. One of the major elements is that it is a retrospective study. It is true that there is a lack of indication for content that requires selection of treatment options, such as Onyx and coil, transarterial and translumbar, and multiple origin selection. Because these choices are the result of reflecting the operator's preferences, it seems difficult to clearly estimate the indication in a retrospective study. Indications for reintervention for T2EL were initially treated when the endoleak was seen, but have recently been changing to reflect the concept that it is observing to wait until the endoleak grows larger than 10 mm. The data organized in this study were intended to follow the 5–10 mm sac enlargement standard as the guidelines.

As another limitation, there was a difference in follow-up after embolization of the 2 groups (Onyx, 11.6 months *vs*. coil, 34.7 months; $P = 0.016$). The endoleak resolve values were 33.3% for Onyx and 38.7% for coil, respectively, 60%–70% of both groups were endoleaks after embolization. There was no significant difference in the time from embolization to reintervention in both groups ($P = 0.465$), so when the follow-up period is extended, the cases of reintervention in the Onyx group are expected to increase. Therefore, according to the log-rank result in Table 3 and the Kaplan-Meier survival curve presented in Fig. 1, it is reasonable to assume that there is no significant difference in the sac growth >5 mm result of the 2 groups. However, the 5-year survival rate of post-EVAR patients is approximately 28%–46% and diseases other than AAA such as heart failure, cardiovascular or pulmonary disease, and malignancy often accompany EVAR, there may be limitations in long-term follow-up studies [30]. Considering the life expectancy of patients post-EVAR, Onyx embolization for T2EL may have a benefit in lowering the risk of early-phase reintervention. Furthermore, coil embolization resulted in a higher risk of sac growth than Onyx embolization through odds ratio analysis, which was not shown in other comparative

studies (P = 0.016). Of course, there is no doubt that further evaluation is needed due to the lack of an Onyx sample number.

Regardless of the follow-up period, this study provides useful results in relation to the embolization technique. There was no significant difference in outcome between transarterial and direct translumbar puncture in the Onyx group (Table 4), indicating that the selection of an access route is not a limiting factor when using Onyx. Also, the lack of difference in sac size at the time of embolization between the 2 groups (Onyx, 66.3 mm *vs.* coil, 67.9 mm; P = 0.657) indicates that sac size is not a technical limitation. The frequent use of Onyx in cases with multiple endoleak origins (Onyx, 33.3% *vs.* coil, 3.2%; P = 0.002) supports the technical usefulness of Onyx.

In conclusion, there appears to be no significant difference in the results of Onyx and coil embolization for T2EL treatment, although it is difficult to evaluate effectiveness due to the small number of cases and short follow-up period. However, in cases of multiple origin endoleaks or when the transarterial approach is not feasible, the Onyx by translumbar approach may be a more effective method.

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Conflict of Interest
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