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Impact of Stent Graft Design on External Iliac Artery Limb Occlusion Rates After Endovascular Aneurysm Repair: Post-hoc Analysis of a Japanese Multicentre Database

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WHAT THIS PAPER ADDS

External iliac artery (EIA) limb deployment during endovascular aortic aneurysm repair (EVAR) is associated with an increased risk of limb occlusion. Japanese patients are thought to have a higher incidence of EIA limb deployment during EVAR and a higher incidence of limb occlusion than Caucasians. It is suggested that a helical stent with expanded polytetrafluoroethylene should be used in patients with a small EIA, such as Japanese patients, to reduce the risk of EIA limb occlusion. Clinicians can put these findings to immediate clinical use. This study also serves as a baseline for similar studies of other stent graft designs.

Objective/Background: It was hypothesised that a helical stent with expanded polytetrafluoroethylene (ePTFE) grafts could provide a preventive effect for external iliac artery (EIA) limb occlusion following endovascular aortic aneurysm repair (EVAR). Therefore, a post-hoc analysis of a Japanese multicentre database was conducted to assess the impact of the stent graft design on EIA limb occlusion rates.

Methods: Patients who underwent EVAR with EIA limb deployment between 2008 and 2016 were evaluated. The stent graft limbs were divided into two groups: group A comprised stent graft limbs made of a helical stent with ePTFE grafts (Excluder; $n = 255$), and group B comprised stent graft limbs made of a Z stent with polyester grafts (Zenith, Flex and Endurant; $n = 173$). The main outcome was the incidence of limb occlusion and severe limb stenosis (EIA related limb complications). The risk factors for EIA related limb complications were analysed and the midterm results between groups A and B compared. Fine–Gray generalisation of the proportional hazards model was used after propensity score matching to calculate the hazard ratio (HR).

Results: One complication occurred in group A and 10 complications occurred in group B. The risk factors for EIA related limb complications for the entire group were a stent graft limb size $\leq$10 mm (HR 5.41; $p = .01$) and inclusion in group B (HR 14.9; $p = .009$). After propensity matching, group A ($n = 159$) was matched with group B ($n = 159$). The cumulative incidence function of EIA related limb complications at five years was 0.66% in group A and 7.8% in group B (HR 8.67; $p = .039$).

Conclusion: Stent graft design can affect limb patency in EIA limb deployment. When EIA limb deployment is necessary for patients with a small EIA, such as Japanese patients, stent graft limbs made of a helical stent with ePTFE should be used to reduce the risk of limb occlusion.

Keywords: Abdominal aortic aneurysm, EIA limb occlusion, Endovascular aortic aneurysm repair, Japanese
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INTRODUCTION

Endovascular aortic aneurysm repair (EVAR) is an established treatment for patients with favourable anatomy who are unfit for open surgery. However the main disadvantage of EVAR is its long term durability with a high incidence of late complications requiring re-intervention. Among these complications, stent graft limb occlusion is the third most common requiring re-intervention after EVAR; its reported incidence ranges from 2.6% to 7.4%.[1,2]

Several studies have shown that external iliac artery (EIA) limb deployment during EVAR is a strong risk factor for limb occlusion.[3–7] When the common iliac artery (CIA) diameter is too large or its length too short, extension of the landing zone into the EIA is necessary. The causes of this higher limb occlusion rate are postulated to be a small diameter of the EIA, EIA tortuosity, and reduced runoff due to occlusion of the internal iliac artery. The risk of limb occlusion ranges from 1.0% to 3.0% when landing in the CIA, whereas it ranges from 7.7% to 12.0% when landing in the EIA.[4–6]

There is a paucity of data comparing long term results of limb occlusion in EIA limb deployment among different stent graft designs. Typical stent graft limbs such as the Zenith, Zenith Flex (Flex; Cook, Bloomington, IN, USA) and Endurant (Medtronic, Santa Rosa, CA, USA) are made from polyester grafts surrounded by a Z stent with unsupported gaps.[8] This unsupported gap is susceptible to kinking and occlusion when placed in a tortuous iliac artery.[6,9] Conversely, stent graft limbs with a helical stent structure such as the Excluder (expanded polytetrafluoroethylene [ePTFE] grafts surrounded by a spiral Z stent; W.L. Gore and Associates, Flagstaff, AZ, USA), Aorfix (polyester grafts surrounded by a spiral stent; Lombard Medical, Irvine, CA, USA), Ovation (PTFE grafts surrounded by a spiral stent; Endologix, Irvine, CA, USA), and Zenith Spiral Z (Spiral Z; polyester grafts surrounded by a spiral Z stent [Cook]) are thought to be flexible and compliant in tortuous vessels.[8,10] Additionally, data have shown that ePTFE stent grafts are less thrombogenic than polyester stent grafts.[11–13]

Previous studies have shown that the EIA diameter is smaller and the CIA length shorter in Asian than in Caucasian individuals.[14,15] Additionally, the morphological features are the same in Japanese as in other Asian individuals.[16] Japanese patients are considered to have a higher probability of EIA limb deployment during EVAR and a higher risk of limb occlusion than Caucasians.

With this background, it was hypothesised that a helical stent with an ePTFE graft, such as the Excluder, could provide a preventive effect for EIA limb occlusion in Japanese patients. In this post-hoc analysis of a Japanese multicentre database, the aim was to identify the risk factors for EIA limb occlusion and to assess the impact of the stent graft design on limb occlusion in EIA limb deployment.

METHODS

Study design and patient population

From January 2008 to December 2016, 1671 patients with an abdominal aortic aneurysm, CIA aneurysm, or both were treated by EVAR using commercially available stent grafts at 10 institutions in Japan. EVAR data were collected and recorded in a prospectively accumulated database. This registry was approved by each institutional review board. Patients who underwent EVAR with EIA limb deployment were evaluated using this database. The starting date was set when the Japanese government approved the use of commercially available stent grafts after 2006, and stent grafts were first used at the authors' institution in January 2008. Thus, first generation stent grafts were not on the market at the time of the present study, and second generation or later stent grafts were used from the beginning of the study period.

During the study period, the stent graft limbs used in EIA limb deployment were the Excluder, Zenith, Flex, Spiral-Z, Endurant, Powerlink (Endologix), and Aorfix. To assess the effect of a small stent graft on EIA limb occlusion, stent graft limbs that do not accept an EIA $<$10 mm were excluded (Powerlink; 21 limbs). To avoid confounding variables, stent graft limbs that were used in only a few patients and were followed up for only a short period were also excluded from this study (Aorfix [16 limbs with a mean $\pm$ SD follow up of 15.4 $\pm$ 7.8 months]; Spiral-Z [13 limbs with a mean $\pm$ SD follow up of 12.5 $\pm$ 5.5 months]). In one Endurant limb, a Fluency stent graft (Bard, Tempe, AZ, USA) was implanted to correct a type Ib endoleak; this patient was also excluded. Finally, the stent graft limbs were divided into two groups: group A comprised patients with stent grafts made from a helical stent with ePTFE grafts; group B comprised patients with stent grafts made from a Z stent with polyester grafts (Fig. 1).

EVAR procedure and post-operative follow up

Each institution had at least one board certified EVAR specialist approved by the Japanese Committee for Stentgraft Management. Although device selection was based on the preference of the physician at each institution, the size of the EIA limb was selected according to the criteria recommended by the manufacturers.

On completion of EVAR with EIA limb deployment, stiff guidewires were routinely removed and completion angiography was performed with or without floppy guidewires to assess limb patency. If limb kinking or stenosis predisposing to limb occlusion was suspected, a bare metal stent (BMS) was implanted based on the judgement of the physician at each institution. To analyse the isolated impact of the stent graft limb design on limb occlusion, EIA limbs with an intra-operatively implanted BMS were excluded.

The use of antiplatelet or anticoagulation agents after EIA limb deployment depended on the physician's judgement at each institution. All patients were encouraged to participate in the surveillance protocol, which included enhanced computed tomography (CT) or unenhanced CT with colour duplex ultrasonography, plain abdominal radiography, and measurement of the ankle brachial index at one, six and 12 months post-operatively and yearly thereafter.

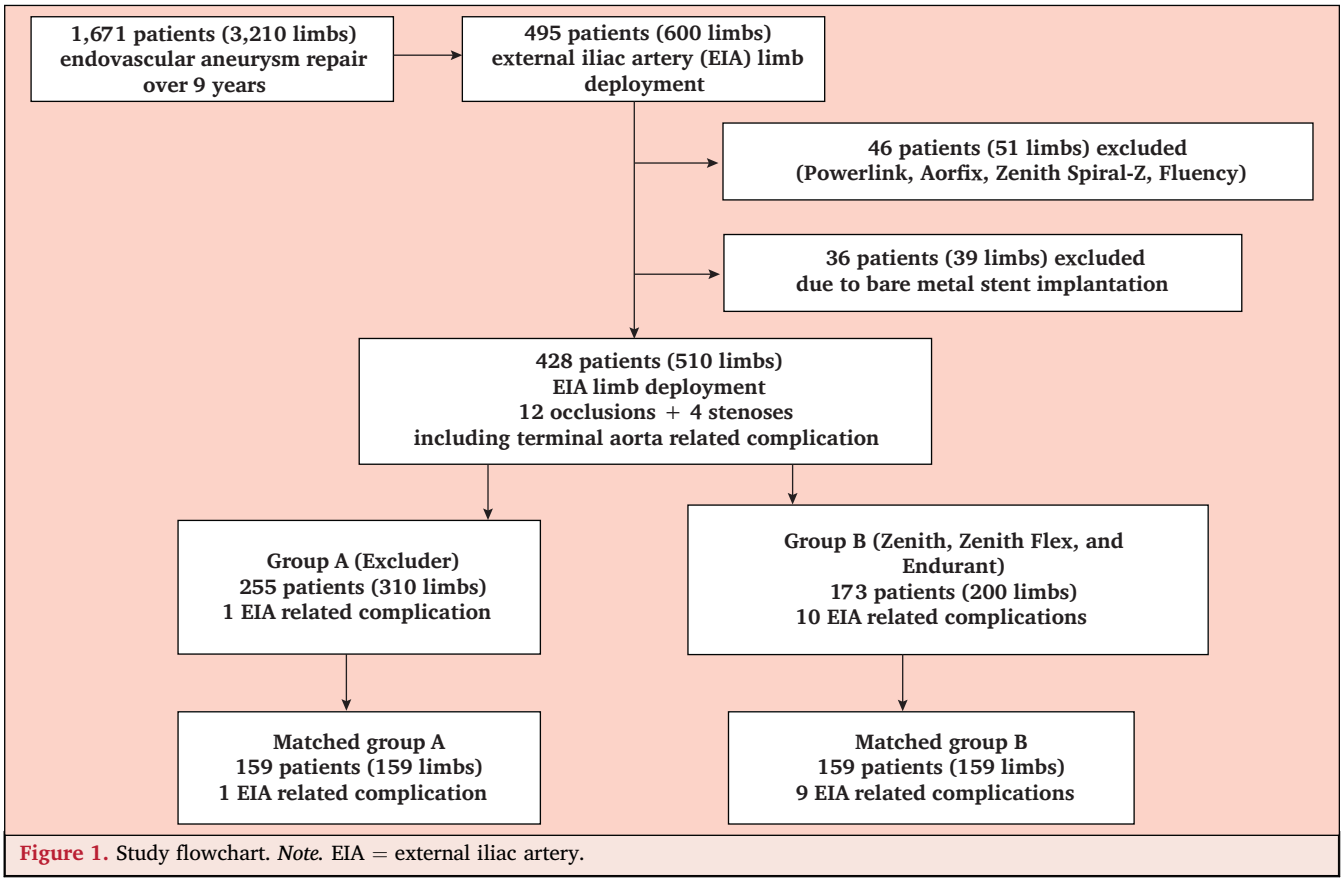

Figure 1. Study flowchart. *Note.* EIA = external iliac artery.

Data collection and definitions

Data were collected on patient characteristics, comorbidities, EIA tortuosity, and procedure related data. It was considered that kinking of the EIA limb occurred at two locations: the EIA itself, and the transition between the EIA and CIA. Severe EIA tortuosity was then defined as the presence of a double iliac sign at these two points on pre-operative CT, according to the method described by Taudorf et al.[17] When more than two EIAs were visualised within the landing zone of the EIA limb (Fig. 2A), or both the distal CIA and proximal EIA were visualised on a single axial CT slice (Fig. 2C), the EIA was considered to have severe tortuosity. The EIA diameter was defined as the distance from intima to intima of the EIA excluding thrombus, at the landing zone of the EIA limb. Dual antithrombotics was defined as a combination of antiplatelet or anticoagulation agents (dual antiplatelet therapy or single antiplatelet therapy plus anticoagulation). To identify the flow dynamics associated with limb thrombosis, changes in the limb's calibre were assessed. Changes in limb calibre were defined as the ratio between the exit (EIA diameter) and entrance of the limb (proximal limb size).

The main outcome was defined as the incidence of limb occlusion and severe limb stenosis necessitating a BMS (EIA related limb complications). Because limb occlusion and limb stenosis necessitating a BMS due to a narrow terminal aorta were unrelated to EIA limb deployment, they were not defined as EIA related limb complications.

Statistical analysis

All data were analysed according to the intention to treat principle. For the baseline variables, summary statistics were constructed using frequencies and proportions for categorical data and means ± SD for continuous variables. Patient characteristics were compared using the chi-square test or Fisher's exact test for categorical outcomes, and *t* tests or the Mann—Whitney *U* test for continuous variables, as appropriate.

For time to event outcome, the cumulative incidence function (CIF) for EIA related limb complications was estimated using a competing risk analysis because death is a competing risk of loss to follow up (i.e., patients who die can no longer become lost to follow up). Also, to identify baseline and clinical variables associated with the primary outcome, competing risk analyses were performed with the Fine—Gray generalisation of the proportional hazards model accounting for death as a competing risk. Receiver operating characteristic curves were used to assess the optimal cut off stent graft size of the EIA limb to predict EIA related limb complications. The follow up index (FUI) between the study groups was calculated. The FUI was defined as the ratio between the investigated follow up period and the theoretically possible follow up period, up to April 2017.

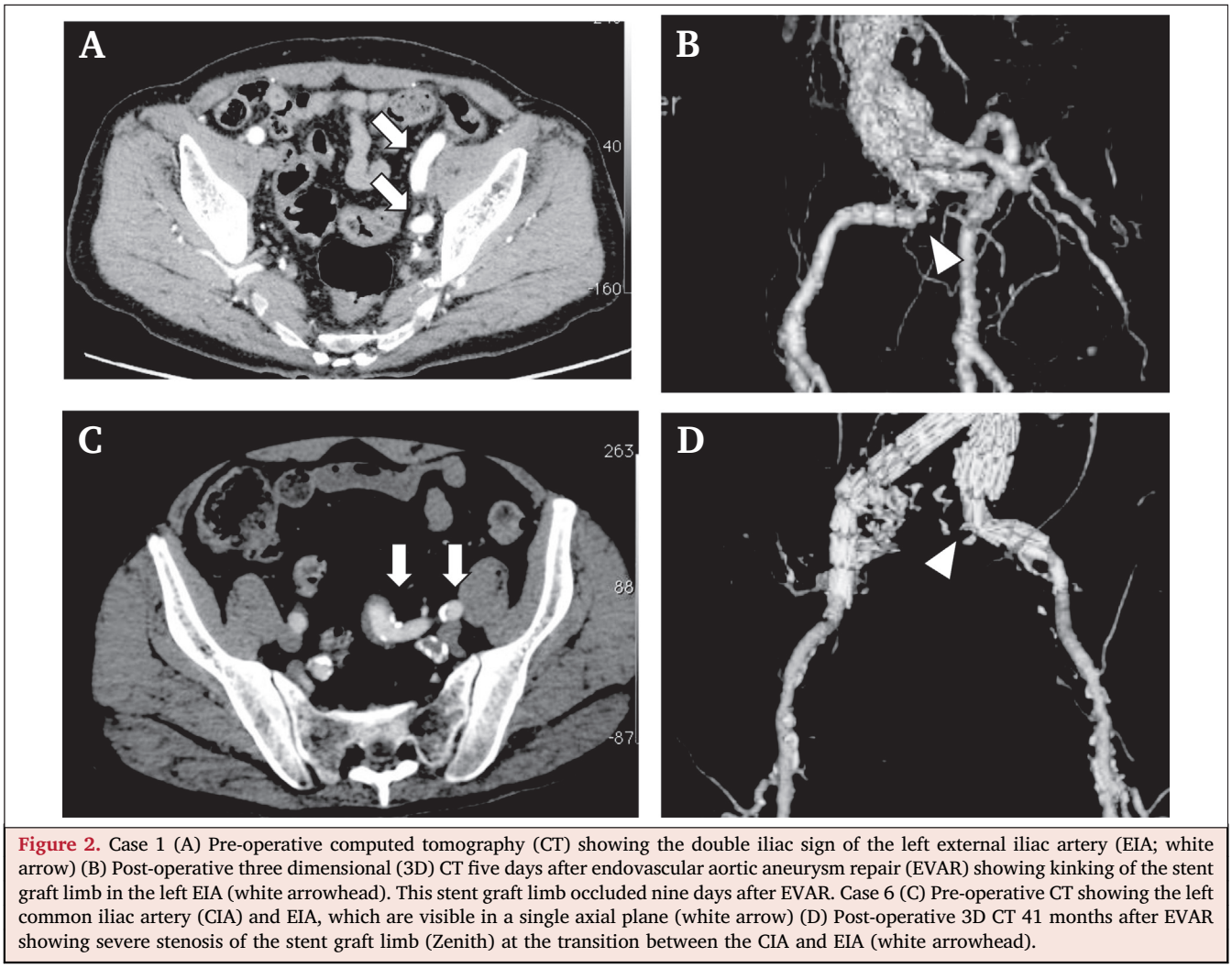

Figure 2. Case 1 (A) Pre-operative computed tomography (CT) showing the double iliac sign of the left external iliac artery (EIA; white arrow) (B) Post-operative three dimensional (3D) CT five days after endovascular aortic aneurysm repair (EVAR) showing kinking of the stent graft limb in the left EIA (white arrowhead). This stent graft limb occluded nine days after EVAR. Case 6 (C) Pre-operative CT showing the left common iliac artery (CIA) and EIA, which are visible in a single axial plane (white arrow) (D) Post-operative 3D CT 41 months after EVAR showing severe stenosis of the stent graft limb (Zenith) at the transition between the CIA and EIA (white arrowhead).

Additionally, to adjust for differences in patient characteristics and risk factors, propensity score matching with a greedy 5 to 1 digit matching algorithm was used. A multiple logistic regression model estimated the predicted probability of initiating a helical stent with ePTFE grafts compared with a Z stent with polyester grafts given the baseline covariates. These covariates included patient characteristics (age and sex), comorbidities (hypertension, diabetes mellitus, coronary artery disease, cerebrovascular disease, chronic obstructive pulmonary disease, haemodialysis, smoking history, antiplatelet therapy, and anticoagulation), EIA tortuosity, and device size.

All statistical tests were two sided, with a p value $< .05$ considered statistically significant. All analyses were performed using SPSS software version 24 (IBM, Armonk, NY, USA) and SAS software, version 9.4 (SAS Institute, Cary, NC, USA).

RESULTS

During the nine year study period, 600 limbs (495 patients) underwent EVAR with EIA limb deployment (total 18.7%: Excluder [23.1%], Zenith and Zenith Flex [13.0%], Endurant [18.7%]) among 3210 limb deployments (CIA + EIA) in this study. Fifty-one limbs (Powerlink, Aorfix, Spiral-Z, Fluency) were excluded from this study. Of the remaining 549 limbs, 39 limbs (36 patients) were intra-operatively implanted with a BMS. The remaining (non-BMS) limbs were divided into two groups: group A (Excluder, 310 limbs [255 patients]); group B (Zenith, Flex, and Endurant, 200 limbs [173 patients]).

The baseline patient characteristics, comorbidities, EIA tortuosity, and procedure related data for each group are shown in Table 1. In the whole study groups, more patients had a small EIA limb size in group B than in group A (42.8% vs. 31.0%; $p = .01$). A propensity score matching analysis was performed to minimise bias associated with this background. After propensity score matching, group A (159 patients) was matched with group B (159 patients).

No limb intra-operative complications occurred among patients implanted with a BMS. More patients had a hostile EIA anatomy in the BMS than in the non-BMS group (severe EIA tortuosity: 30.6% vs. 14.8% [$p = .01$]; limb size $\leq$ 10 mm: 52.8% vs. 35.4% [$p = .04$]) (Table S1; see Supplementary Material).

Twelve limb occlusions and four severe limb stenoses necessitating a BMS occurred in the 549 limbs with a non-

Table 1. Baseline patient characteristics, comorbidities, external iliac artery tortuosity, and procedure related data

	Entire study group			Propensity matched groups		
	Group A (n = 255)	Group B (n = 173)	p	Group A (n = 159)	Group B (n = 159)	p
Patient characteristics						
Age (y)	76.7 ± 9.1	76.7 ± 9.1	.65	76.7 ± 9.5	76.6 ± 8.0	.88
Male sex	204 (80.0)	147 (85.0)	.19	132 (83.0)	135 (84.9)	.65
Follow up (mo)	28.6 ± 22.2	31.4 ± 22.7	.21	28.8 ± 22.9	31.4 ± 21.9	.30
Follow up index	0.73 ± 0.29	0.71 ± 0.31	.54	0.71 ± 0.30	0.71 ± 0.30	.91
Comorbidities						
Hypertension	182 (71.4)	124 (71.7)	.95	115 (72.3)	113 (71.1)	.80
Diabetes Mellitus	30 (11.8)	19 (11.0)	.80	17 (10.7)	18 (11.3)	.86
Coronary artery disease	69 (27.1)	58 (33.5)	.15	54 (34.0)	51 (32.1)	.72
Cerebrovascular disease	40 (15.7)	38 (22.0)	.10	33 (20.8)	34 (21.4)	.89
Chronic obstructive pulmonary disease	24 (9.4)	23 (13.3)	.21	20 (12.6)	20 (12.6)	1.0
Haemodialysis	10 (3.9)	8 (4.6)	.72	8 (5.0)	8 (5.0)	1.0
Smoking history	128 (50.2)	83 (48.0)	.65	69 (43.4)	75 (47.2)	.50
Antiplatelet therapy	95 (37.3)	80 (46.2)	.06	68 (42.8)	71 (44.7)	.73
Anticoagulation	28 (11.0)	13 (7.5)	.23	13 (8.2)	13 (8.2)	1.0
Dual antithrombotics	36 (14.1)	25 (14.5)	.92	25 (15.7)	23 (14.5)	.75
Severe external iliac artery tortuosity	33 (12.9)	30 (17.3)	.21	24 (15.1)	26 (16.4)	.76
Limb device			—			—
Excluder	255 (100)			159 (100)		
Zenith or Zenith Flex		89 (51.4)			85 (53.5)	
Endurant		84 (48.6)			74 (46.5)	
External iliac artery diameter (mm)	8.53 ± 1.40	8.32 ± 1.21	.11	8.46 ± 1.40	8.34 ± 1.23	.43
Limb diameter ≤ 10 mm	79 (31.0)	74 (42.8)	.01	65 (40.9)	64 (40.3)	.91
Limb oversizing (%)	40.3 ± 24.7	41.4 ± 23.3	.64	38.1 ± 24.3	41.9 ± 23.1	.15
Change in limb calibre	0.65 ± 0.14	0.65 ± 0.11	.90	0.65 ± 0.11	0.65 ± 0.14	.61
External iliac artery related complication	1 (0.4)	10 (5.8)	.01	1 (0.6)	9 (5.7)	.02

Note. Data are presented as mean ± standard deviation (SD) for continuous variables and n (%) for categorical variables.

BMS. Among these complications, 11 EIA related limb complications occurred. One complication occurred in group A and 10 complications occurred in group B. Details are presented in Table 2. Three EIA limbs became occluded and one EIA limb became stenosed because of kinking (Fig. 2A and B [case 1]; Fig. 2C and D [case 6]). Two EIA limbs occluded because of poor transition of the distal portion in the EIA limbs to the native artery (Fig. 3A [case 9]). Two EIA limbs became stenosed because of mural thrombus (Fig. 3B and C [case 10]). No patient with EIA related limb complications showed fabric infolding at the landing zone of the EIA limb on enhanced CT images obtained immediately after EVAR. Pre-operative findings in all patients with EIA related limb complications showed that the ankle brachial index results and superficial femoral artery (SFA) runoff were normal.

The optimal stent graft diameter cutoff of the EIA limb to predict EIA related limb complications was 10.5 mm as determined by calculation using receiver operating characteristic curves (sensitivity 0.665; specificity 0.727; area under the curve 0.683). The stent graft diameter of the EIA limb was then divided into two groups: ≤ 10 and > 10 mm.

Univariable Fine—Gray proportional sub-hazards analysis in whole study groups revealed that a stent graft limb diameter ≤10 mm and inclusion in group B were risk factors for EIA related limb complications (limb diameter ≤ 10 vs. > 10 mm; hazard ratio [HR] 5.41, 95% confidence interval [CI] 1.54—20.1 [p = .01]; group B vs. group A limb device: HR 14.9, 95% CI 1.95—114 [p = .009]) (Table 3). In the multivariable analysis, a stent graft limb diameter ≤10 mm and inclusion in group B were risk factors for EIA related limb complications.

After propensity score matching, CIF of EIA related limb complications at five years was significantly different between matched groups A and B (0.66% in group A vs. 7.8% in group B; HR 8.667, 95% CI 1.15—67.344 [p = .04]) (Fig. 4). The mean FUI was similar between matched groups (0.71 ± 0.30 in group A vs. 0.71 ± 0.31 in group B; p = .91) (Table 1).

DISCUSSION

The EIA limb deployment rate (18.7%) in this study is higher than that in previous non-Asian studies (8.8—13.7%).[4—6] Additionally, the average EIA diameter in the present study was 8.4 mm, which is smaller than the diameter reported in Caucasians.[14,15] The smallest stent grafts (≤ 10 mm) were used in 35.4% of EIA limb deployments. Taking these facts into account, suitable pre-operative strategies are needed for Japanese patients to reduce the risk of iliac limb occlusion during EVAR.

When pre-operative CT shows severe EIA tortuosity or completion angiography shows narrowing of the stent grafts because of kinking, adjunctive BMS EIA limb

Table 2. Details of EIA related limb complications

Case	Event	Cause	Time	Limb device	External iliac artery (mm)	Limb diameter (mm)	Tortuosity	Antiplatelet therapy	Oral anticoagulation	Treatment
1	Occlusion	Kinking	9 d	Endurant	9.0	10	Yes	SAPT	No	Femoro-femoral (F–F) bypass
2	Occlusion	Unidentified	3 mo	Excluder	7.2	10	No	No	No	Conservative
3	Occlusion	Unidentified	15 mo	Zenith	8.0	10	No	SAPT	No	F–F bypass
4	Stenosis	Mural thrombus	30 mo	Zenith Flex	10.0	12	No	No	No	Stent
5	Occlusion	Poor transition	22 d	Endurant	8.0	10	No	No	No	F–F bypass
6	Stenosis	Kinking	41 mo	Zenith	9.0	10	Yes	DAPT	No	Stent
7	Occlusion	Kinking	8 d	Zenith	9.0	10	Yes	DAPT	Yes	F–F bypass
8	Occlusion	Unidentified	15 mo	Zenith Flex	10.0	12	No	SAPT	Yes	F–F bypass
9	Occlusion	Poor transition	21 d	Endurant	8.7	10	No	No	No	F–F bypass
10	Stenosis	Mural thrombus	12 mo	Zenith	8.6	10	No	No	No	Stent
11	Occlusion	Kinking	10 d	Zenith Flex	12.0	16	Yes	No	No	Stent

Note. Time = time to event; EIA (mm) = external iliac artery (EIA) diameter; tortuosity = severe EIA tortuosity; SAPT = single antiplatelet therapy; DAPT = dual antiplatelet therapy; F–F = femoro–femoral.

implantation during EVAR is a possible technique by which to reduce the limb occlusion rate.[5,18] In the present study, no limb complications occurred in the BMS group. However, it is not practical to use a BMS for all EIA limbs during EVAR, and no definite criteria have been established regarding which limbs or sites BMS implantation should occur.[6] It is considered that the best strategy with which to reduce the risk of EIA limb occlusion is to ensure optimal selection of the stent graft limb.

In the present study, 12 limb occlusions occurred (2.2%), including terminal aorta related occlusions. Although this limb occlusion rate is better than that of previous studies (7.7–12.0%), this finding is difficult to interpret because the rates of BMS implantation and types of stent grafts used were different among the studies.[4–6] Therefore, patients who underwent BMS implantation and patients with limb occlusion due to a narrow terminal aorta were excluded to allow for analysis of the isolated impact of the stent graft design on EIA limb occlusion.

The Zenith, Flex, Excluder, and Endurant were the most commonly used devices. Although these second generation stent grafts differ in material and design, their performance was excellent compared with the first generation stent grafts and very similar to that in multicentre studies.[7,14,19] However, there are no long term results regarding the performance of these devices in patients with a complex iliac anatomy. In this study, the performance of these devices under EIA limb deployment following EVAR was evaluated.

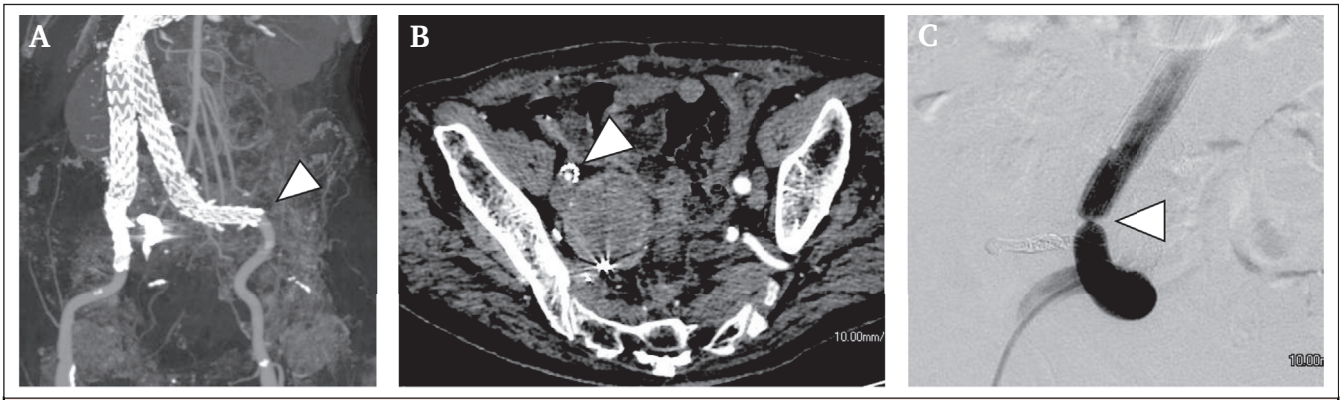

Figure 3. Case 9 (A) Post-operative three dimensional computed tomography (CT) three days after endovascular aortic aneurysm repair (EVAR) showing that the distal edge of the stent graft limb is hitting the curvature of the left external iliac artery (white arrowhead). This stent graft limb became occluded 21 days after EVAR. Case 10 (B) Post-operative CT showing mural thrombosis in the stent graft limb (white arrowhead) (C) Angiography showing severe stenosis of the stent graft limb (white arrowhead).

Table 3. Univariable and multivariable Fine–Gray proportional sub-hazards analysis of variables affecting the risk of external iliac artery related limb complications in the whole group

Variable	Univariable analysis		Multivariable analysis	
	Hazard ratio (95% confidence interval)	*p*	Hazard ratio (95% confidence interval)	*p*
Age				
≥ 80 vs. < 80 y	1.78 (0.54–5.85)	.34	1.83 (0.53–6.33)	.33
Sex				
Female vs. male	NA	NA	NA	NA
Comorbidities				
Hypertension	0.98 (0.26–3.69)	.97	0.78 (0.18–3.33)	.74
Diabetes mellitus	NA	NA	NA	NA
Coronary artery disease	2.70 (0.73–8.82)	.09	3.01 (0.61–14.8)	.17
Cerebrovascular disease	2.70 (0.73–8.82)	.37	0.83 (0.14–4.75)	.84
Chronic obstructive pulmonary disease	1.96 (0.44–8.77)	.38	0.76 (0.14–4.16)	.75
Haemodialysis	2.52 (0.32–19.7)	.37	0.63 (0.004–94.9)	.85
Smoking	1.25 (0.38–4.06)	.71	0.82 (0.23–2.86)	.76
Antiplatelet therapy	1.18 (0.37–3.82)	.77	9.28 (0.31–278)	.19
Anticoagulation	1.15 (0.15–8.89)	.89	1.66 (0.02–130)	.81
Dual antithrombotics	1.98 (0.51–7.76)	.32	0.05 (0.001–1.71)	.10
Limb device				
Group A vs. Group B	14.9 (1.95–114)	.009	13.7 (1.33–139)	.02
Severe external iliac artery tortuosity				
Yes vs. no	2.92 (0.86–9.86)	.08	3.60 (0.76–17.1)	.11
Limb diameter				
≤ 10 vs. > 10 mm	5.41 (1.54–20.1)	.01	6.54 (1.49–28.7)	.01

NA = Not Applicable.

Unlike previous studies, the present study failed to show severe EIA tortuosity to be a significant risk factor.[2,20] This discrepancy may have been attributable to the small number of patients or to selection bias, given that a BMS was implanted in many EIA limbs with severe tortuosity. Another reason was the definition of iliac tortuosity. The definition described by Taudorf et al. was adopted because it was considered to be simple and efficient in the actual clinical setting.[17] No validated methods with which to describe iliac tortuosity are currently available; a new reliable method is needed.[21]

Four complications due to stent graft limb kinking occurred in the present study. All cases of stent graft limb kinking were characterised by severe EIA tortuosity on preoperative CT, and all limb occlusions occurred in the early period (8–10 days post-operatively) after EVAR. This observation is consistent with previous studies that warned of the importance of careful observation of the limb status in EIA limb deployment in patients with severe EIA tortuosity.[22,23]

Two EIA limbs became occluded because of poor transition of the distal portion in the EIA limb to the native artery. No patients had severe EIA tortuosity, but the distal edge of the stent graft limb was positioned just at the curvature of the EIA. In such cases, extension of the BMS beyond the stent graft is advisable to create a smooth transition between the stent graft and native artery.[5]

Two cases of severe EIA limb stenosis due to mural thrombosis were found. Previous studies have suggested that an abrupt change in the calibre of the conduit or a small distal limb causes turbulent flow and increases the risk of mural thrombosis after EVAR.[24,25] In the present study, there were no significant differences in changes in limb calibre between the study groups. Additionally, polyester fabric seems to develop more intra-prosthetic thrombus accumulation than ePTFE fabric after EVAR, which may be related to differences in fabric thrombogenicity.[12,13] Considering this mechanism of thrombus formation, EIA limb deployment (especially in a small EIA) with a polyester fabric stent graft is thought to be associated with a high risk of thrombus formation. Furthermore, a longer main body may be related to mural thrombosis.[12,24] In the current study, severe stenosis of the EIA limb secondary to mural thrombosis occurred with the Zenith and Zenith Flex, which have longer main bodies than the Excluder. Although no validated evidence has shown that mural thrombi are related to stent graft occlusion,[12,13,25] particular care is required when following EIA limbs with mural thrombi; regular use of duplex scanning or enhanced CT is recommended.[26]

Previous studies have shown that excessive oversizing of a stent graft can lead to infolding of the graft material within the graft lumen; this has been linked to limb occlusion.[1,3] Mantas et al. reported that ≥15% stent graft oversizing against the CIA is a risk factor for limb occlusion.[1] Although there was no significant difference in stent graft oversizing between study groups, in the current study average stent graft oversizing against EIA was 40.8%, which suggests a high risk of limb occlusion after EIA limb deployment in Japanese patients.

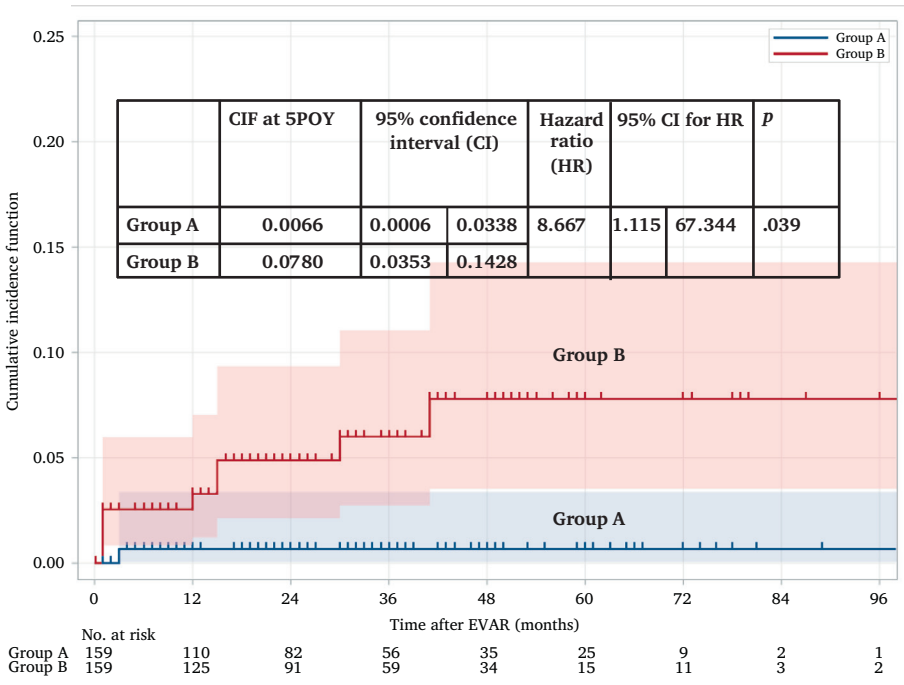

Figure 4. Cumulative incidence function of external iliac artery related limb complications between patients in matched group A and group B. *Note.* CIF = cumulative incidence function; POY = postoperative year; CI = confidence interval; HR = hazard ratio; EVAR = endovascular aortic aneurysm repair.

SFA runoff was a possible risk factor for limb occlusion; however, SFA runoff was normal in all patients with EIA related limb complications. Additionally, another study failed to identify SFA runoff as a risk factor for limb occlusion.[17] Therefore, the present authors believe that SFA runoff is not a risk factor.

A stent graft limb diameter ≤10 mm was a strong risk factor for EIA related limb complications in the current study. This finding is consistent with that of a previous study. Carroccio et al. demonstrated that a limb diameter ≤14 mm was associated with limb occlusion.[4] Faure et al. also showed that an EIA of ≤10 mm when the limb had a kink was a predictive factor for limb occlusion.[7]

It is believed that the excellent results in group A were mainly for two reasons. One reason is the helical stent structure, which is thought to be resistant to kinking in a tortuous EIA. This resistance to kinking was proven by fine element analysis, which showed that a helical stent structure is more flexible than a Z stent structure.[8] The other reason is that ePTFE grafts are less thrombogenic than polyester grafts. The combination of a helical stent structure and ePTFE graft may provide a preventive effect against EIA limb occlusion.

One of the limitations of the present study is its retrospective and non-randomised design. Stent graft selection and the decision regarding whether to perform BMS implantation or to use antiplatelet or anticoagulation agents after EIA limb deployment were dependent upon the preference of the physician at each institution, which may have resulted in a significant bias in both groups. Additionally, the Aorfix and Spiral-Z were excluded from this study because of the small number of patients with such devices, and the Ovation (Endologix) was not included because this device had not been released in Japan at the time of the study. The Aorfix and Spiral-Z are made of a helical stent structure with polyester grafts and the Ovation comprises a helical stent structure with PTFE. Further studies using those devices are needed to assess the superiority of the helical stent structure with an ePTFE graft over another stent graft design. Unfortunately, the Spiral-Z will soon be withdrawn from the market in Japan and replaced by the Zenith-Alpha Spiral-Z, which is not yet available. Such frequent changes in devices contributed to the small number of cases for a particular device, which is an additional limitation of the study. Moreover, the study was limited to Japanese patients; it is difficult to apply the results to Caucasians with abdominal aortic aneurysms that differ morphologically. Finally, the study was exploratory; the limited number of patients and low event rate decreased the statistical power. Further accumulation of similar studies is necessary to confirm the present results.

CONCLUSION

This study evaluated EIA limb occlusion rates after EVAR among second generation stent grafts and showed that a small stent graft limb and the Z stent design with a polyester graft were risk factors for EIA limb occlusion. A helical

stent design with an ePTFE graft could prevent limb occlusion for patients with a small EIA, such as Japanese patients.

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CONFLICT OF INTEREST

None.

APPENDIX A. SUPPLEMENTARY DATA

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