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Original Article

Effect of the Terminal Aortic Diameter on the Patency Rate of Iliac Limbs after Endovascular Aortic Repair

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Objective: Endograft limb occlusion (ELO) is a complication of endovascular aneurysm repair (EVAR). In this study, we investigated the mechanism and anatomical features of ELO.
Materials and Methods: We retrospectively reviewed 227 consecutive patients with abdominal aortic aneurysm who underwent EVAR between 2007 and 2017. We then analyzed the preoperative risk factors and anatomical features of patients with ELO.
Results: A total of nine patients had ELO (4.0%). The diameter of the terminal aorta was significantly smaller in patients with ELO than in patients without ELO (18.0 mm vs. 22.3 mm, p=0.039). We measured the diameter of each limb near the terminal aorta. The smaller limb (SL) was occluded in all patients with occlusion. The difference between the larger limb (LL) and the SL (LL-SL) was significantly larger in patients with ELO than in patients without ELO (4.0 mm vs. 1.7 mm, p<0.001). The following were considered risk factors for ELO: younger age, narrow terminal aorta, severe calcification at the terminal aorta, and use of an Endurant device.
Conclusion: ELO occurs when the diameter of one side of the stent graft limb is small compared with the diameter of the other side owing to the narrow terminal aorta and calcification.

Keywords: abdominal aortic aneurysm, endovascular aneurysm repair, endograft limb occlusion

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Introduction

Endovascular aneurysm repair (EVAR) has many advantages over open surgery. However, some complications have been reported.[1,2] One known complication is endograft limb occlusion (ELO), which has a reported incidence of 0%–7.2%.[3] Tortuosity, calcification, significant angulation, and landing in the external iliac artery (EIA) have been suggested to be risk factors of ELO.[1] Although a narrow terminal aorta was reported to be a risk factor, the cause of this phenomenon has not been well described.[4] The present study aimed to identify the potential anatomical risk factors of ELO by using a case-control design and to investigate the mechanism of ELO in a narrow terminal aorta.

Methods

Data on all consecutive patients treated by EVAR in our hospital between August 2007 and June 2017 were retrospectively reviewed. The maintenance of this data set was approved by our Institutional Review Board (No. 20150117). The indication for EVAR was abdominal aortic aneurysm (AAA) with a maximum aneurysm diameter >5.0 cm, a rapidly growing AAA, or an irregularly shaped saccular aneurysm. Ruptured AAA cases were excluded in this study. EVAR was the first-line therapy for AAA. Patients with a short proximal neck or difficult access routes were treated surgically. When selecting the treatment methods, the anatomical feature of the terminal aorta, including its diameter or the degree of calcification, was not considered. EVAR was performed even in patients with a narrow terminal aorta. In patients with an unfavorable landing zone in the common iliac artery, the distal landing zone of the stent grafts was located in the EIA following internal iliac artery coil embolization. Commercially available devices were used during the treatment period. The size of the stent graft was decided by referring to the diameter of the proximal landing and distal landing. Under general anesthesia, both sides of the femoral arter-

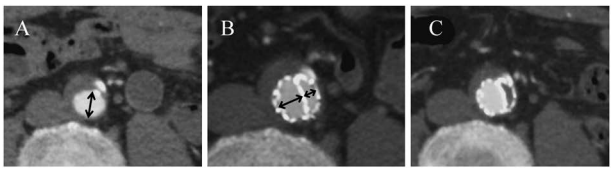

Fig. 1 The preoperative and postoperative computed tomography (CT) of the narrow terminal aorta of one patient.
(**A**) The short axis of the intralumen diameter of the terminal aorta preoperatively (arrow). (**B**) One-week postoperative CT. A large difference in the diameter between the right and left limbs (arrows) was created at the terminal aorta after stent graft deployment. (**C**) Two-month postoperative CT. The smaller side of the stent graft limb was subsequently occluded.

ies were exposed, and the devices were inserted. We used a balloon expansion system to attach the stent graft to the aortic wall. Both of the stent graft limbs were dilated fully separately after stent graft deployment. The kissing balloon technique was not used. Completion angiography was performed to identify any endoleaks or occlusion of the limbs and native arteries. Contrast computed tomography (CT) angiography was routinely performed 1 week postoperatively, at 6 months, at 12 months, and annually. Morphologic analysis and the measurement of the aneurysm based on CT angiography were performed preoperatively and postoperatively. We measured the short axis of the intralumen diameter of the terminal aorta preoperatively (**Fig. 1A**). The short axis of each stent graft limb was measured at the terminal aorta level one week postoperatively (**Fig. 1B**). The stent graft limbs that have smaller diameters at the terminal aorta were defined as the smaller limb (SL), and those with larger diameters at the terminal aorta were defined as the larger limb (LL). In the case of EPL/AFX, the diameter of stent graft limbs immediately after branching was measured. The degree of aortic tortuosity was assessed using the double iliac sign.[5] The terminal aorta was classified by the degree of calcification as the ratios of calcified wall length to the whole circumference of the terminal aorta. Two independent observers (YI and AY) performed all image analyses. Stent graft occlusions were identified as symptomatic during the postoperative hospital stay after EVAR, at hospital visits during follow-up, or at emergency department visits. Stent graft occlusion was confirmed by CT. All patients with limb occlusion were treated surgically or endovascularly.

Statistical analysis

The mean and standard deviation (SD) were used for summarizing continuous variables with a symmetric distribution. The median and range were used for describing nonsymmetrical distributions. Numbers and percentages were used for indicating categorical variables. Continuous variables were compared using Student's t-test, and categorical variables were compared using Fisher's exact test if any cell had a count <5 in a contingency table; otherwise, the chi-squared test was used. Kaplan–Meier analysis was performed to describe limb patency. All tests were two sided, and a p-value <0.05 indicated a statistically significant difference. All statistical calculations were performed using IBM SPSS Statistics Ver. 25 (SPSS Inc., Chicago, IL, USA).

Results

During the 10 years from 2007 to 2017, 227 patients were treated for AAA by EVAR. The number of male patients was 183 (80.6%). The mean age at the time of primary EVAR was 75.0 ± 8.7 years. All procedures were performed and/or planned by one surgeon. The devices included Endurant (n = 91), Endurant2 (n = 2), EPL/AFX (n = 25), Excluder (n = 35), Talent (n = 7), Zenith (n = 65), and Zenith Flex (n = 2). During the follow-up, nine patients had ELO (9/227; 4.0%). The median follow-up months from EVAR was 37.1 months (Interquartile Range (IQR): 20.0–61.5). The median months from EVAR to occlusion was 2.8 months (IQR: 1.9–10.4). Five patients and seven patients had graft occlusions in three months and within one year, respectively. The primary graft limb patency was 99.6% at six months, 96.7% at one year, and 95.4% at three years (**Supplement 1**). All patients presented with symptoms at the time of limb occlusion. Five patients had intermittent claudication (Fontaine classification IIb). Four patients had ischemic rest pain (Fontaine classification III). Femorofemoral bypass was performed in five emergency cases or difficult-to-treat cases endovascularly, and embolectomy with stent placement was performed in four elective cases. All occluded limbs in nine patients were restored. There were no amputations. All bypassed grafts and additional endografts were patent in the follow-up time. **Table 1** shows the patients' demographic and risk factors. The patients who developed ELO were significantly younger than the patients who did not develop ELO (age: 69.2 years vs. 75.3 years, p = 0.04). For the remaining factors, there were no significant differences between limb occlusion and gender, smoking history, chronic obstructive pulmonary disease, diabetes mellitus, pulmonary disease, hypertension, medical history of stroke, and body mass index. CT angiography measurement shows that the diameters of the terminal aorta of the patients with occlusion were significantly smaller than those of the patients without occlusion (18.0 mm vs. 22.3 mm, p = 0.039). The diameters of the AAA, proximal landing zone, and distal landing zone and the presence of the EIA landing showed no significant difference. The SL was occluded in all patients with occlusion (**Fig. 1C**). The diameter of the SL of the patients with occlusion was sig-

Table 1 Baseline characteristics of patients and the abdominal aorta anatomy pattern investigated for association with endograft limb occlusion and summary of the endograft devices used

	Total patients (n=227)	Patients with occlusion (n=9)	Patients without occlusion (n=218)	p-value
Male patients	183 (80.6%)	7 (77.8%)	176 (80.7%)	0.687
Age (y)	75.0±8.7	69.2±10.2	75.3±8.5	**0.04**
BMI	22.6±3.4	24.0±2.7	22.5±3.4	0.197
Smoker	142 (62.6%)	6 (66.7%)	136 (62.4%)	1
COPD	64 (28.2%)	3 (33.3%)	61 (28.0%)	0.714
DM	34 (15.0%)	3 (33.3%)	31 (14.2%)	0.136
Hypertension	164 (72.2%)	6 (66.7%)	158 (72.5%)	0.711
Stroke	23 (10.1%)	0	23 (10.6%)	0.604
EIA landing	33 (14.5%)	3 (33.3%)	30 (13.8%)	0.127
Antiplatelet	119 (52.4%)	4 (44.4%)	115 (52.8%)	0.739
Anticoagulant	22 (9.7%)	0	22 (10.1%)	0.605
Proximal landing diameter	21.9±3.7	22.1±2.5	21.9±3.8	0.885
AAA diameter	50.1±8.2	49.7±8.2	50.1±8.2	0.887
Landing diameter (right)	13.8±3.8	12.4±3.6	13.8±3.8	0.282
Landing diameter (left)	13.9±3.8	15.0±5.4	13.8±3.8	0.378
Terminal aorta diameter	22.1±6.1	18.0±7.4	22.3±6.0	**0.039**
Diameter of the LL	11.8±2.6	11.3±2.9	11.8±2.6	0.539
Diameter of the SL	10.0±2.3	7.3±3.2	10.1±2.2	**<0.001**
LL-SL	1.8±1.6	4.0±1.8	1.7±1.5	**<0.001**
SL/LL	0.9±0.1	0.63±0.2	0.86±0.1	**<0.001**
Calcification at the terminal aorta <1/3	170 (74.9%)	4 (44.4%)	166 (76.1%)	**0.046**
Calcification at the terminal aorta >2/3	15 (6.6%)	3 (33.3%)	12 (5.5%)	**0.016**
Double iliac sign	7 (3.1%)	1 (11.1%)	6 (2.6%)	0.155
Common iliac artery angle >60°	39 (17.2%)	2 (22.2%)	37 (17.0%)	0.654
Device				
Endurant	91 (40.1%)	7 (77.8%)	84 (38.5%)	**0.032**
Endurant2	2 (0.9%)	0	2 (0.9%)	1
EPL/AFX	25 (11.0%)	1 (11.1%)	24 (11.0%)	1
Excluder	35 (15.4%)	0	35 (16.1%)	0.361
Talent	7 (3.1%)	0	7 (3.2%)	1
Zenith	65 (28.6%)	1 (11.1%)	64 (29.4%)	0.452
Zenith Flex	2 (0.9%)	0	2 (0.9%)	1

The values are expressed as numbers (%) or mean±SD.
BMI: body mass index; COPD: chronic obstructive pulmonary disease; DM: diabetes mellitus; EIA: external iliac landing; AAA: abdominal aortic aneurysm; LL: larger limb; SL: smaller limb

nificantly smaller than that of the patients without occlusion (7.3 mm vs. 10.1 mm, $p<0.001$). The difference in the diameter between the LL and SL (LL-SL) was significantly larger in patients with occlusion than in patients without occlusion (4.0 mm vs. 1.7 mm, $p<0.001$). The SL/LL ratio was significantly low in patients with occlusion compared with patients without occlusion (0.63 vs. 0.86, $p<0.001$). The right limb in five patients, the left limb in three patients, and both limbs in one patient were occluded. The main body in three patients and the contralateral body in six patients were occluded. Significant differences in the percentage of calcification at the terminal aorta <1/3 (44.4% vs. 76.1%; $p=0.046$) and >2/3 (33.3% vs. 5.5%; $p=0.016$), as well as in Endurant (Medtronic Cardiovascular, CA, USA) cases (77.8% vs. 38.5%; $p=0.032$), were observed. The double iliac sign, which indicates severe tortuosity, iliac angle >60°, and EIA landing, was not recognized as an ELO risk factor. In the graft-specific analysis, although the preoperative diameters of the AAA and terminal aorta were slightly large in the Endurant graft compared with the other grafts, the difference in the diameter between the LL and SL (LL-SL) was significantly large in the Endurant graft compared with the other grafts (2.3 mm vs. 1.5 mm, $p<0.001$) (**Table 2** and **Fig. 2**).

Table 2 Baseline characteristics of patients and the abdominal aorta anatomy pattern of Endurant and other grafts

	Endurant graft (n=91)	Other grafts (n=136)	p-value
Limb occlusion	7 (7.7%)	2 (1.5%)	**0.032**
Male patients	75 (82.4%)	108 (79.4%)	0.611
Age	75.6±8.3	74.7±8.9	0.456
BMI	22.8±3.1	22.5±3.6	0.501
Smoker	61 (67.0%)	81 (59.6%)	0.267
COPD	31 (34.1%)	33 (24.3%)	0.132
DM	19 (20.9%)	15 (11.0%)	0.057
Hypertension	68 (74.7%)	96 (70.6%)	0.547
Stroke	14 (15.4%)	9 (6.6%)	0.043
EIA landing	14 (15.4%)	19 (14.0%)	0.848
Antiplatelet	62 (68.1%)	57 (41.9%)	**<0.001**
Anticoagulant	10 (11.0%)	12 (8.8%)	0.65
Proximal landing diameter	22.2±3.6	21.8±3.8	0.427
AAA diameter	52.3±7.6	48.5±8.2	**0.001**
Landing diameter (right)	14.8±4.4	13.1±3.2	**0.003**
Landing diameter (left)	14.4±4.3	13.5±3.5	0.105
Terminal aorta diameter	23.4±7.3	21.3±5.0	**0.02**
LL-SL	2.3±1.9	1.5±1.2	**<0.001**
Calcification at the terminal aorta >1/3	19 (20.9%)	37 (27.2%)	0.346
Double iliac sign	4 (4.4%)	3 (2.2%)	0.442
Common iliac artery angle >60°	23 (25.3%)	16 (11.8%)	**0.011**

The values are expressed as numbers (%) or mean±SD.
BMI: body mass index; COPD: chronic obstructive pulmonary disease; DM: diabetes mellitus; EIA: external iliac landing; AAA: abdominal aortic aneurysm; LL: larger limb; SL: smaller limb

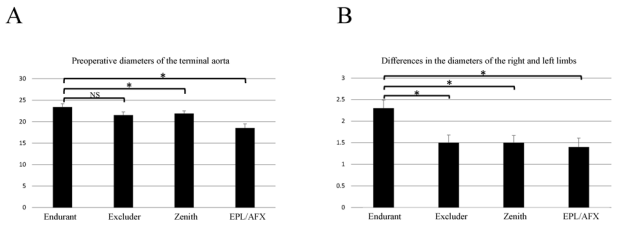

Fig. 2 Graft-specific analysis using computed tomography.
(**A**) Preoperative diameters of the terminal aorta in the Endurant, Excluder, Zenith, and EPL/AFX cases. (**B**) Differences in the diameters of the right and left limbs at the terminal aorta level of the Endurant, Excluder, Zenith, and EPL/AFX cases. NS, not significant; *, p<0.05.

Discussion

The number of EVAR-related complications and secondary procedures has increased in the follow-up period. In some case series, the incidence rate of limb occlusion was reported to range from 0% to 7.2%.[3] In this report, the limb occlusion rate was 4.0%. This rate is almost the same frequency as that of other reports. Iliac tortuosity, calcification, significant angulation, narrow terminal aorta, and landing in the EIA have been suggested as risk factors of ELO.[1–5] In the present study, a young age and a narrow terminal aorta similarly were correlated with a significantly high rate of limb occlusion. In cases of limb occlusion, there were large differences in the diameter of each limb at the terminal aorta. With the Endurant graft, there was a tendency for the occurrence of some differences in the diameter of each limb at the terminal aorta compared with other grafts in the patients with occlusion or without occlusion. To the best of our knowledge, these anatomical features have never been described in previous reports.

The asymmetry of each limb was thought to be influenced by the narrow terminal aorta and severe calcification. Given that severe calcification reduces the capacity for enlargement of the aorta and increases the intra-aortic radial force after limb graft deployment, the large difference in the diameter between the right and left limbs may be caused by the radical force between both limb grafts. There were no specific criteria in selecting stent graft devices. Considering the result in **Fig. 2A**, there may have been a tendency to select EPL/AFX or Zenith in the case of a narrow terminal aorta. Even though the preoperative diameter of the terminal aorta in the Endurant group was significantly larger than that of other grafts, there were greater differences in each limb diameter with the Endurant device. It is speculated that the difference in radial force of each limb (stent graft overlapping limb and non-overlapping limb) is greater in the Endurant device than in the other devices. The other speculation in the En-

durant device is that one side of the stent graft (secondary expansion) might excessively push the other side of the stent graft (primary expansion). Intraoperative completion angiography should be performed under a rotational view, in which the angle and tortuous iliac arteries are perpendicularly visualized.[3] In the case of a narrow terminal aorta, a kissing balloon or an additional bare stent graft deployment should be performed if there is a large difference in the diameter between the limbs. It is very difficult to visualize the compressed limb intraoperatively in the completion angiogram unless one uses intravascular ultrasound (IVUS). In Japan, the use of two similarly sized balloons and IVUS in one EVAR operation is not covered by health insurance. Thus, we could not perform the kissing balloon technique and IVUS analysis.

Both the endovascular approach and extra-anatomical bypass are acceptable for the treatment of aortic ELO.[6] Although the endovascular approach is an attractive option, this procedure is time consuming and may be complicated by leg embolism and dislodgement of the stent graft, which can result in new endoleaks. As noted in a previous study, extra-anatomical bypass is very effective for the treatment of aortic ELO, with a resulting patency rate $>90\%$.[7] Extra-anatomical bypass should be performed for emergency cases with acute thrombosis or cases that were difficult to treat endovascularly. Embolectomy with stent placement should be performed for chronic and Fontaine classification IIb cases.

The limitations of this study include the small sample size and its retrospective design. Some patients with limb occlusion may have been missed, such as those with only mild symptoms or no symptoms. Furthermore, selection bias likely occurred when selecting the type of endografts. However, the case-control study design allowed for robust findings. To fully take into consideration the probability of limb occlusion, a prospective cohort design should be used in the next study.

Conclusion

A narrow terminal aorta with severe calcification occasionally creates a large difference in the diameter between both limbs. A high risk for occlusion occurs when the diameter of one side of the stent graft limb is very small compared with the diameter of the other side of the stent graft limb. In particular, the Endurant stent tends to create a large difference in the diameter between limbs at the terminal aorta. Patients with a narrow terminal aorta should be carefully followed after primary EVAR.

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Disclosure Statement

All authors have no conflicts of interest to declare.

Author Contributions

Study conception: YI, AY, HS
Data collection: all authors
Analysis: YI, AY
Investigation: YI
Writing: YI
Funding acquisition: none
Critical review and revisions: all authors
Final approval of the article: all authors
Accountability for all aspects of the work: all authors

Supplementary Information

Supplementary figure is available at the online article sites on J-STAGE and PMC.

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