New morphological factor for predicting late proximal type I endoleak after endovascular aneurysm repair.

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ABSTRACT

Background: Although we have witnessed several cases of late proximal type I endoleak (T1AEL) after endovascular aneurysm repair (EVAR), most patients did not have "hostile neck" preoperatively. We hypothesized that the distance between the lowest renal artery and the neck angulation point and neck length are the two most important factors for maintaining long-term proximal sealing. This study evaluated "neck hostility", which is the product of the distance to the angulation point and the neck length, as a preoperative morphological risk factor for the development of late T1AEL after EVAR.

Methods: A retrospective review of a prospectively assembled database was performed for all patients who had undergone EVAR at a single institution from June 2007 to May 2017. Patient demographics and preoperative imaging data were collected, and Cox regression analysis was performed to identify the risk factors for late T1AEL.

Results: Of the 655 patients who underwent EVAR during the study period, 115 were excluded due to complex EVAR (n=14), primary indications for iliac aneurysms (n=86), primary T1AEL (n = 3), or other reasons (n=15). Of the remaining 537 patients, twelve patients (2.2%) developed late T1AEL a median of 3.2 (interquartile range [IQR]; 3.0, 5.4) years after EVAR. Receiver operating characteristic (ROC) curve analysis revealed a neck hostility cutoff value of 8. Cox regression analysis revealed that a neck hostility value ≤ 8 and conical neck anatomy were risk factors for the development of late T1AEL after EVAR. Well-known hostile neck factors such as short neck, severe angulated neck, and severe calcification/thrombus in the proximal neck were not significantly different.

Conclusions: The present study demonstrated a correlation between late T1AEL and the product of the angulation distance and the neck length. This factor may be useful for predicting poor late proximal outcomes after EVAR.

Keywords: EVAR, AAA, Hostile neck, Endoleak, type Ia endoleak

INTRODUCTION

Endovascular aneurysm repair (EVAR) has become a standard treatment for abdominal aortic aneurysm (AAA) and has significantly improved short-term outcomes compared with open surgical repair (OSR).[1–3] However, this procedure can fail in the long term, partly due to the interdependence of endograft sealing and the morphological aspects of the proximal aortic neck. Accordingly, manufacturers traditionally have defined a short proximal neck length (< 10 mm or < 15 mm), severe neck angulation (> 60°), or significant thrombus and/or calcification as outside their instructions for use (IFUs). These IFUs, however, have been based on benchtop research and aimed to achieve immediate optimal outcomes after EVAR.

The term "hostile neck" was first advocated by the Pittsburgh group in 2003 to characterize outcomes after EVAR in patients with unfavourable neck anatomy.[4] The term is currently used when the aortic anatomy is beyond the eligibility criteria for manufacturers' regulatory clinical trials. However, nearly half (47.6%) of cases violate the IFUs in clinical practice.[5] The impact of each factor on late proximal outcomes after EVAR is not clear because various outcomes have been reported in regards to the association between hostile neck anatomy and late proximal type I endoleak (T1AEL).[6–9]

Although we have experienced several cases of late proximal type I endoleak (T1AEL) after EVAR, most were without "hostile neck" anatomy preoperatively. In clinical settings, a short proximal neck, including conical neck anatomy, is of course challenging for primary proximal sealing, but a severely angulated neck, which is included in the hostile neck criteria, is not so difficult if the angulation point is far from the lowest renal artery. Accordingly, we hypothesized that the distance between the lowest renal artery and the neck angulation point and neck length are the two most important factors for maintaining proximal sealing in the long term. The purpose of this study was therefore to evaluate a factor multiplied by these two factors as a preoperative morphological factor associated with late T1AEL after EVAR.

METHODS

The Nagoya University Institutional Review Board approved this study (2019-0096), and the need for individual patient consent was waived since all data were obtained from routine clinical care.

Study population

Patients who underwent elective EVAR for infrarenal AAA between June 2007 and May 2017 at our institution were reviewed. The indication for repair was AAA ≥ 5 cm in diameter, a rapidly growing aneurysm (≥ 5 mm per 6 months), or a saccular aneurysm. In principle, EVAR was applied to patients older than 75 years of age or patients at high risk with OSR even if they were younger than 75 years of age.[10] Patients with targeted aneurysms located in the abdominal aorta (not the iliac artery) and treated with a commercially available bifurcated endograft were included in this study. Patients treated in the emergent setting and patients who required concomitant procedures to the renal artery, including chimney/snorkel or fenestrated/branched techniques, were excluded. Patients who were observed to have primary T1AEL conservatively were also excluded from this study (in contrast, patients who were treated immediately after the detection of primary T1AEL on postoperative computed tomography (CT) angiography were included).

Study/follow-up protocol and procedures

Patient baseline demographics, comorbidities, medications, operative details, and outcomes were collected. All patients underwent CT angiography with three-dimensional reconstruction before surgery. All procedures were performed in a fully equipped operating room with the patients under regional or general anaesthesia and with fluoroscopic guidance. Patients underwent CT angiographies (if renal function permitted) or plain CT with Doppler ultrasound tests at 3, 6, and 12 months and annually thereafter.

Image analysis

A 3D imaging workstation (TeraRecon, Inc., Durham, NC) was used to generate multiple 3D reconstructions of volumetric data sets from preoperative CT angiography scans. A greater curve line was extracted automatically after generating a 3D aortic lumen centerline (a greater curve line is indicated as a yellow line in **Figure 1A**, and a centerline is indicated as a yellow line in **Figure 1B**).

Definitions

Preoperative coronary artery disease (CAD) was defined as an abnormal result on coronary angiography and a history of myocardial infarction or open or percutaneous coronary artery revascularization. Chronic obstructive pulmonary disease (COPD) was identified by pulmonary function studies or active treatment with medication.

Hypertension (HT), dyslipidaemia (DL), and diabetes were identified in patients undergoing active medical treatment or diet modification. Cerebrovascular disease (CVD) was defined as a history of stroke, transient ischaemic attack, or carotid intervention.

In this study, the angulation point was defined as the point perpendicular to the greater curve line at 45 degrees from just below the lowest renal artery. Then, the angulation distance (mm) was measured to be the greater curve line length from the lowest renal artery to the angulation point (**Figure 1A**). An angulation distance over 50 mm and aortic angulation less than 45 degrees were set to 50 mm as the angulation distance. Neck length was defined as the centerline length between the level of the lowest renal artery and the level where the diameter of the infrarenal aortic neck exceeded that at the lowest renal artery by 10%. “Neck hostility” was defined as the neck length x the angulation distance/100. A short neck was defined as an infrarenal neck length less than 15 mm. Other hostile neck factors were commonly used factors. Severe angulation was defined as infrarenal proximal neck angulation greater than 60 degrees. Severe calcification was defined as a ≥50% calcified proximal neck, and severe thrombus was defined as a ≥50% circumferential proximal neck thrombus (≥2 mm). The term “hostile neck” was used if 1 or more of three proximal neck factors (short proximal neck, severe angulation, or severe calcification/thrombus) were present. A conical neck was defined as gradual neck dilatation ≥ 2 mm within the first 10 mm below the lowest renal artery. A large neck was indicated when the patient was treated with a main body ≥ 31 mm in proximal diameter.

Data analysis

All statistical analyses were performed using JMP pro statistical software version 15 (SAS Institute Inc., Cary, NC, USA). For comparisons, categorical variables were analysed using a chi-square test or Fisher's exact test as appropriate. Continuous variables were analysed using Student's *t*-test or the Mann-Whitney test as appropriate. Cox proportional hazard analysis was applied for the univariate analysis of risk factors for the development of late T1AEL. Analysis of the receiver operating characteristic (ROC) curves was used to determine the cutoff value of "neck hostility" for late T1AEL, and the area under the ROC curve (AUC) provides a measure of the factor "neck hostility" to discriminate between patients who developed late T1AEL and those who did not. Freedom from late T1AEL was assessed using Kaplan-Meier life-table analysis, and a log-rank test was performed. All p values were two-sided, with $p < 0.05$ regarded as indicative of statistical significance.

RESULTS

During the study period, a total of 655 patients underwent EVAR at our institution. Among them, 115 patients were excluded from the study, namely, due to complex EVAR (n=14), treatment with aorto-uni-iliac devices (n=6) or aortic cuffs (n=7), primary indications for iliac aneurysms (n=86), or other reasons (n=2). In addition, three patients who developed primary T1AEL were excluded because the primary endpoint of this study was late proximal type I endoleak. As a result, 537 patients were ultimately included in this study. Patient demographics are shown in **Table 1**. There was no inhospital death, and the primary technical success rate was 100% (Note: three patients with primary type I endoleaks who were observed conservatively were excluded from this study). The preoperative morphological characteristics are detailed in **Table 2**. Approximately 30% of patients had hostile neck anatomy, and of those, ten patients had two hostile neck criteria. Implanted devices are also shown in **Table 2**. The median follow-up duration was 4.0 (interquartile range [IQR]; 2.1, 6.0) years. Among the study cohort, twelve patients (2.2%) developed late T1AELs a median of 3.2 (IQR; 3.0, 5.4) years after EVAR (one was due to distal migration of endografts). As a result, one patient died of AAA rupture, and another patient was observed to have late T1AEL because of the recurrence of malignant disease. Of the remaining ten patients, nine were treated successfully by proximal aortic extension, and one required open prosthetic graft replacement (**Table 3**).

ROC curve analysis

ROC curve analysis of neck hostility revealed that the AUC for the predicted probabilities was 0.79 (95% confidence interval [CI]: 0.66-0.87). At the optimal cutoff value of 8, the sensitivity of the minimum neck hostility for predicting late T1AEL was 75.0% with 78.1% specificity (**Figure 2**). Accordingly, we determined a neck hostility value of 8 or less to be a hostile neck factor and compared it with other popular hostile neck criteria. There were 124 (23.1%) patients with neck hostility values ≤ 8 in the study cohort.

Univariate analysis

Univariate Cox regression analysis revealed a conical neck anatomy (P = .013, hazard ratio [HR]: 4.269, 95% CI: 1.352-13.478) and neck hostility value ≤ 8 (P =.0003, HR: 11.168, 95% CI: 3.019-41.308) to be significant preoperative morphological risk factors for late T1AEL (**Table 4**). Well-known hostile neck criteria such as short neck, severe angulation, severe calcification/thrombus, conical neck, and large neck were not statistically significant as discriminators of late T1AEL. Subsequent multivariate analysis could not be performed owing to the small number of cases that developed late T1AELs.

Freedom from late proximal type I endoleaks

The Kaplan-Meier survival curve of the freedom from late T1AEL is shown in Figure 2. At the 4-year follow-up, the estimated rate of freedom from late T1AEL was 99.2% (n = 2; standard error [SE], 0.0055) in the neck hostility group with values >8 and 92.0% (n = 6; SE, 0.081) in the neck hostility group with values ≤8 (log rank test; P <.0001) (**Figure 3**).

DISCUSSION

This is the first report advocating for the use of the factor "neck hostility", which multiplies two factors, angulation distance and neck length, as a predictor of late T1AEL. The term "hostile neck" was coined by Dillavou et al in their study to determine a suitable neck anatomy for successful EVAR.[4] In current clinical settings, the term is used when the proximal aortic anatomy is excluded from the eligibility criteria for manufacturers' regulatory clinical trials (IFUs). However, these criteria are based on benchtop and clinical research by manufacturers only for securing optimal immediate outcomes after EVAR, and whether these hostile neck criteria impact long-term outcomes remains controversial.

In terms of proximal neck length, there is no room for discussion about its hostility. However, most surgeons do not seem to face much difficulty when using the latest endograft for severe angulation, which is a factor of the so-called hostile neck anatomy. In fact, even if the angulation is severe, the most recently developed endografts conform well, and the long-term results are good when the distance to the angulation point is long enough (**Figure 1C, D**). If the distance to the angulation point is short and there is a short neck length, even the most recently developed endografts cannot conform to it, and proximal sealing becomes poor. In contrast, if the distance to the angulation point is short but the proximal neck length is long enough, good sealing can be achieved. Based on the above, we hypothesized that the factor obtained by multiplying the neck length by the distance to the angulation point might have an impact on proximal sealing in the late period, which was evaluated in this study.

Regarding the angulation point, we initially determined the angulation point based on the centerline and started studying the distance to it. However, even if the centerline is actually angled, proximal sealing can be improved by aligning the stent graft with the proximal neck when there is sufficient space on the greater curve of the aortic lumen. In contrast, if the greater curve is also severely angulated, it becomes difficult to place the stent graft coaxially in the aorta proximal to the angulation point. Therefore, we determined the angulation point of the greater curve line and found that the angulation distance to that point was important.

In the 3D workstation, the greater curve line can be drawn automatically. The degree of change from the perpendicular plane at the lowest renal artery level to the angulation point was examined preliminarily at 30, 45, and 60 degrees, and we concluded that 45 degrees was the degree of clinical difficulty. As a result, we determined 45 degrees to be the threshold value in this study.

The hostile neck criteria are essentially anatomic criteria for clinical decision making to obtain primary success. Although there are several studies investigating the impacts of hostile neck anatomy on post-EVAR outcomes, most of them are studies of intraoperative or short-term outcomes.[11–13] The impacts of “so-called” hostile neck anatomy or each factor of challenging neck on late outcomes are diverse. Jordan et al investigated a study population with challenging neck anatomy enrolled in the ANCHOR trial and concluded that neck diameter and length were predictive of T1AEL (including primary T1AEL, though), but mural thrombus was protective.[14] Antoniou et al conducted a meta-analysis of the outcomes after EVAR in patients with hostile versus favourable neck anatomy and reported that patients with hostile anatomy had a fourfold increased risk of developing T1AEL[8]. However, this analysis was of events within 30 days and at most 1 year. In contrast, AbuRahma reported that there was no significant difference in the incidence of late T1AEL between hostile and favourable neck anatomy. Limited to neck length, Bastos Goncalves et al reported that a neck length <10 mm was a significant risk factor for postoperative neck-related adverse events corresponding to T1AEL. However, most events occurred within one year after surgery.[15] AbuRahma et al also reported that neck length <10 mm was an independent risk factor for late T1AEL.[7] Several studies have reported the association between a large neck and postoperative

T1AEL.[6,16–18] They reported that a large proximal neck was associated with not only delayed T1AEL but also lower survival. A conical neck is also a well-known risk factor for T1AEL, and this was the second strongest risk factor for late T1AEL in our study. Pitoulias et al also reported that this anatomy is strongly associated with proximal neck failure after EVAR, but most T1AELs in their study developed within one month after EVAR. Although there are some reports that the development of T1AEL is not influenced by neck angulation (similar to our findings),[19] others have suggested that aortic curvature is a better parameter than angulation to predict late T1AEL.[20]

Even in the endovascular era, we have OSR as an alternative, and accordingly, we should aim to eradicate late aneurysm-related death after EVAR (which is extremely rare after OSR). There are several types of endoleaks that cause aneurysm sac growth after EVAR, and at present, an increase in aneurysm diameter occurs at a constant rate, which is difficult to predict before surgery. Among those endoleaks, proximal type I endoleak is the most dangerous and difficult to repair. If a morphological factor, such as "neck hostility" in this study, that can predict late T1AEL, is identified, patients with good long-term outcome after EVAR can be identified preoperatively. As a result, this less invasive treatment for AAA can be applied to more patients, with better long-term outcomes. Therefore, the factor "neck hostility" might be helpful in achieving better late outcomes when surgeons are making decisions related to repair planning.

The present study had several limitations. First, our study was a nonrandomized, retrospective, observational study conducted at a single institution. Thus, the findings presented herein are susceptible to unmeasured confounding factors, referral bias, and other potential biases. Second, because the number of patients who developed late T1AEL was quite small, multivariate analysis was not performed. In addition, the cut-off value of 8 for "neck hostility" was calculated based on a small sample size. The primary purpose of this study is not to propose a cutoff value for neck hostility of 8, but rather it is to focus on the use of the product two factors, neck length and angulation distance, as a predictor of late T1AEL after EVAR. Larger scale data and image analysis are required in future work.

CONCLUSIONS

In this study, we presented a new morphological factor, namely, "neck hostility", which multiples two factors, the angulation distance and neck length, and demonstrated a correlation between this factor and the development of late T1AEL. To the best of our knowledge, the present study is the first to use the distance to the angulation point in the greater curve of the proximal aortic neck as a factor in predicting late T1AEL. Further studies utilizing similar approaches are expected to improve late outcomes after EVAR.

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1 Becquemin JP, Pillet JC, Lescalie F, Sapoval M, Goueffic Y, Lermusiaux P, et al. A randomized controlled trial of endovascular aneurysm repair versus open surgery for abdominal aortic aneurysms in low- to moderate-risk patients. *J Vasc Surg* 2011;**53**(5):1167-1173.e1. Doi: 10.1016/j.jvs.2010.10.124.

2 Blankensteijn JD, de Jong SECA, Prinssen M, van der Ham AC, Buth J, van Sterkenburg SMM, et al. Two-Year Outcomes after Conventional or Endovascular Repair of Abdominal Aortic Aneurysms. *N Engl J Med* 2005;**352**(23):2398–405. Doi: 10.1056/NEJMoa051255.

3 Participants ET. Comparison of endovascular aneurysm repair with open repair in patients with abdominal aortic aneurysm (EVAR trial 1), 30-day operative mortality results: randomised controlled trial. *Lancet* 2004;**364**:843–8. Doi: 10.1016/S0140-6736(04)16979-1.

4 Dillavou ED, Muluk SC, Rhee RY, Tzeng E, Woody JD, Gupta N, et al. Does hostile neck anatomy preclude successful endovascular aortic aneurysm repair? *J Vasc Surg* 2003;**38**(4):657–63. Doi: 10.1016/S0741-5214(03)00738-9.

5 Hoshina K, Ishimaru S, Sasabuchi Y, Yasunaga H, Komori K. Outcomes of Endovascular Repair for Abdominal Aortic Aneurysms. *Ann Surg* 2019;**269**(3):564–73. Doi: 10.1097/sla.0000000000002508.

6 Stather PW, Sayers RD, Cheah A, Wild JB, Bown MJ, Choke E. Outcomes of endovascular aneurysm repair in patients with hostile neck anatomy. *Eur J Vasc Endovasc Surg* 2012;**44**(6):556–61. Doi: 10.1016/j.ejvs.2012.10.003.

7 AbuRahma AF, Yacoub M, Mousa AY, Abu-Halimah S, Hass SM, Kazil J, et al.

Aortic Neck Anatomic Features and Predictors of Outcomes in Endovascular Repair of Abdominal Aortic Aneurysms Following vs Not Following Instructions for Use. *J Am Coll Surg* 2016;**222**(4):579–89. Doi: 10.1016/j.jamcollsurg.2015.12.037.

8 Antoniou GA, Georgiadis GS, Antoniou SA, Kuhan G, Murray D. A meta-analysis of outcomes of endovascular abdominal aortic aneurysm repair in patients with hostile and friendly neck anatomy. *J Vasc Surg* 2013;**57**(2):527–38. Doi: 10.1016/j.jvs.2012.09.050.

9 Cerini P, Guzzardi G, Divenuto I, Parziale G, Brustia P, Carriero A, et al. Are abdominal aortic aneurysms with hostile neck really unsuitable for EVAR? Our experience. *Radiol Medica* 2016;**121**(6):528–35. Doi: 10.1007/s11547-016-0620-y.

10 Yamamoto K, Komori K, Banno H, Narita H, Kodama A, Sugimoto M. Validation of patient selection for endovascular aneurysm repair or open repair of abdominal aortic aneurysm: Single-center study. *Circ J* 2015;**79**(8):1699–705. Doi: 10.1253/circj.CJ-14-1160.

11 Chaikof EL, Fillinger MF, Matsumura JS, Rutherford RB, White GH, Blankensteijn JD, et al. Identifying and grading factors that modify the outcome of endovascular aortic aneurysm repair. *J Vasc Surg* 2002;**35**(5):1061–6. Doi: 10.1067/mva.2002.123991.

12 Grisafi JL, Rahbar R, Nelms J, Detschelt EL, Chess BA, Benckart DH, et al. Challenging neck anatomy is associated with need for intraoperative

endovascular adjuncts during Endovascular Aortic Aneurysm Repair (EVAR). *Ann Vasc Surg* 2011;**25**(6):729–34. Doi: 10.1016/j.avsg.2011.02.028.

13 Torsello G, Troisi N, Donas KP, Austermann M. Evaluation of the Endurant stent graft under instructions for use vs off-label conditions for endovascular aortic aneurysm repair. *J Vasc Surg* 2011;**54**(2):300–6. Doi: 10.1016/j.jvs.2010.12.062.

14 Jordan WD, Ouriel K, Mehta M, Varnagy D, Moore WM, Arko FR, et al. Outcome-based anatomic criteria for defining the hostile aortic neck. *J Vasc Surg* 2015;**61**(6):1383-1390.e1. Doi: 10.1016/j.jvs.2014.12.063.

15 Bastos Goncalves F, Hoeks SE, Teijink JA, Moll FL, Castro JA, Stolker RJ, et al. Risk factors for proximal neck complications after endovascular aneurysm repair using the endurant stentgraft. *Eur J Vasc Endovasc Surg* 2015;**49**(2):156–62. Doi: 10.1016/j.ejvs.2014.10.003.

16 Gargiulo M, Gallitto E, Wattez H, Verzini F, Bianchini Massoni C, Loschi D, et al. Outcomes of endovascular aneurysm repair performed in abdominal aortic aneurysms with large infrarenal necks. *J Vasc Surg* 2017;**66**(4):1065–72. Doi: 10.1016/j.jvs.2017.01.066.

17 Howard DPJ, Marron CD, Sideso E, Puckridge PJ, Verhoeven ELG, Spark JI. Editor’s Choice – Influence of Proximal Aortic Neck Diameter on Durability of Aneurysm Sealing and Overall Survival in Patients Undergoing Endovascular Aneurysm Repair. Real World Data from the Gore Global Registry for Endovascular Aortic Treatment (GREAT. *Eur J Vasc Endovasc Surg* 2018;**56**(2):189–99. Doi: 10.1016/j.ejvs.2018.03.027.

18 Oliveira NFG, Gonçalves FB, Ultee K, Pinto JP, Josee van Rijn M, Raa S Ten, et al. Patients with large neck diameter have a higher risk of type IA endoleaks and aneurysm rupture after standard endovascular aneurysm repair. *J Vasc Surg* 2019;**69**(3):783–91. Doi: 10.1016/j.jvs.2018.07.021.

19 Oliveira NFG, Bastos Gonçalves FM, De Vries JPPM, Ultee KHJ, Werson DAB, Hoeks SE, et al. Mid-term results of EVAR in severe proximal aneurysm neck angulation. *Eur J Vasc Endovasc Surg* 2015;**49**(1):19–27. Doi: 10.1016/j.ejvs.2014.10.001.

20 Schuurmann RCL, Van Noort K, Overeem SP, Ouriel K, Jordan WD, Muhs BE, et al. Aortic Curvature Is a Predictor of Late Type Ia Endoleak and Migration after Endovascular Aneurysm Repair. *J Endovasc Ther* 2017;**24**(3):411–7. Doi: 10.1177/1526602817700378.

Table 1. Patient demographics

	Total (n = 537)
Age, years	79 (74, 82)
Male sex	446 (83.1)
Comorbidities	
HT	396 (73.7)
DL	230 (42.8)
Diabetes	60 (11.2)
CAD	164 (30.5)
CVD	79 (14.7)
CKD ≥G3b*	124 (23.1)
Dialysis	13 (2.4)
COPD	255 (47.5)
Current smoker	81 (15.1)
Medicines	
Antiplatelet agent	203 (37.8)
Anticoagulation agent	38 (7.1)
Statin	204 (38.0)
β-blocker	105 (19.6)
CCB	272 (50.7)
ACEI/ARB	220 (41.0)

ACEI, angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; CAD, coronary artery disease; CCB, calcium-channel blocker; CI, confidence interval; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; CVD, cerebrovascular disease; DL, dyslipidaemia; HT, hypertension.

Data are presented as the median (interquartile range) or number (%).

*CKD ≥ G3b indicates eGFR < 45 ml/min/1.73 m^2.

Table 2. Preoperative morphological characteristics and implanted devices

	Total (n = 537)
Aneurysm diameter (mm)	52 (50, 58)
Proximal neck length (mm)	27 (20, 35)
Hostile neck	157 (29.2)
No. of hostile neck criteria	
1	147 (27.3)
2	10 (1.9)
Hostile neck factors	
Short neck	38 (7.1)
Severe angulation	124 (23.1)
Severe calcification/thrombus	5 (0.9)
Conical neck	82 (15.3)
Large neck	66 (12.3)
Proximal adjunctive procedure	85 (15.8)
Angulation distance (mm)	50 (50, 50)
Neck hostility	1250 (850, 1650)
Device type	
Gore Excluder	199 (37.1)
Cook Zenith	156 (29.1)
Medtronic Endurant	136 (25.3)
Endologix Powerlink/AFX	22 (4.1)
Lombard Aorfix	11 (2.0)
Cordis Incraft	8 (1.5)
Medtronic Talent	5 (0.9)

The definitions of the morphological factors are detailed in the main body of the manuscript.

Data are presented as the median (interquartile range) or number (%).

Table 3. Details of cases developed late type Ia endoleak

No.	Aortic neck diameter (mm)	Diameter of endograft (mm)	Sac behaviour*	Type of repair	Outcomes
1	28	32	Growth	Observation***	Death
2	20	23	Growth	PE	Success
3	24	28	Shrinkage**	PE	Success
4	27	30	Growth	PE	Success
5	25	28	Growth	Open conversion	Success
6	23	26	Growth	PE	Success
7	30	23	Growth	PE	Success
8	25	28	Shrinkage**	PE with chimney	Success
9	20	25	Growth	PE with fenestration	Success
10	32	25	Growth	PE with chimney	Success
11	23	28	Growth	Open conversion	Death
12	32	36	Growth	PE	Success

*Sac behaviour at the time of late type Ia endoleak development.

**These two cases developed type Ia endoleak when the significantly reduced aneurysm expanded.

***This case was observed to have late type Ia endoleak because of the recurrence of malignant disease.

PE, proximal extension

Table 4. Univariate Cox regression analysis of the preoperative morphological risk factors for late proximal type I endoleak.

Factors	***P* value**	**HR**	**95% CI**
Hostile neck (#1 or #2 or #3)	.120	2.499	.788 – 7.923
Short neck (#1)	.634	1.647	.212 – 12.820
Severe neck angulation (#2)	.129	2.546	.761 – 8.510
Severe calcification/thrombus (#3)	.999	0.000	.000
Conical neck	**.013**	4.269	1.352 – 13.478
Large neck	.473	1.744	.382 – 7.963
Proximal adjunctive procedure	.999	0.000	.000
Neck hostility value ≤ 8	**.0003**	11.168	3.019 – 41.308

Hostile neck anatomy was indicated when one or more of three proximal neck factors (short neck, severe infrarenal neck angulation, and severe neck calcification/thrombus) were present. A short neck was defined as an infrarenal neck length less than 15 mm. Severe neck angulation was defined as infrarenal neck angulation greater than 60°. Severe neck calcification/thrombus was defined as either calcified proximal neck 50% or more or circumferential proximal neck thrombus (≥2 mm) 50% or more. A conical neck was indicated when neck dilatation was 2 mm or more within the first 10 mm after the lowest renal artery. A large neck was indicated when the patient was treated with a main body 31 mm or more in the proximal neck diameter.

Boldface *P* values represent statistical significance ($P < .05$)

Figure legends

Figure 1. Illustration (A) and CT angiography images (B, C, D, E) of the angulation distance. (**A**) The angulation point was defined as the point perpendicular to the greater curve at 45° just below the lowest renal artery. The angulation distance was measured as the greater curve length from the lowest renal artery to the angulation point. An angulation distance greater than 50 mm and aortic angulation less than 45° was set to 50 mm as the angulation distance. Figure 1B and C shows a case with a short angulation distance (23 mm). This case developed late type Ia endoleak, which resulted in death by rupture five years after the initial surgery. Figure 1D and 1E shows another case with a relatively short and severe angulated neck but a long angulation distance (80 mm). This case obtained significant sac shrinkage with sustained good proximal sealing.

Figure 2. Receiver operating characteristic (ROC) curve analysis of neck hostility for the prediction of late type Ia endoleak. The area under the curve (AUC) for the predicted probabilities was 0.79. The sensitivity was 75.0% and the specificity was 78.1% at the optimal cutoff value of 8.

Figure 3. Kaplan-Meier survival curve for freedom from late type Ia endoleak. At the 4-year follow-up, the estimated rate of freedom from late T1AEL was 99.2% in the neck hostility group with values >8 and 92.0% in the neck hostility group with values ≤8 (log-rank test; *P* <.0001).

Figure 1 A

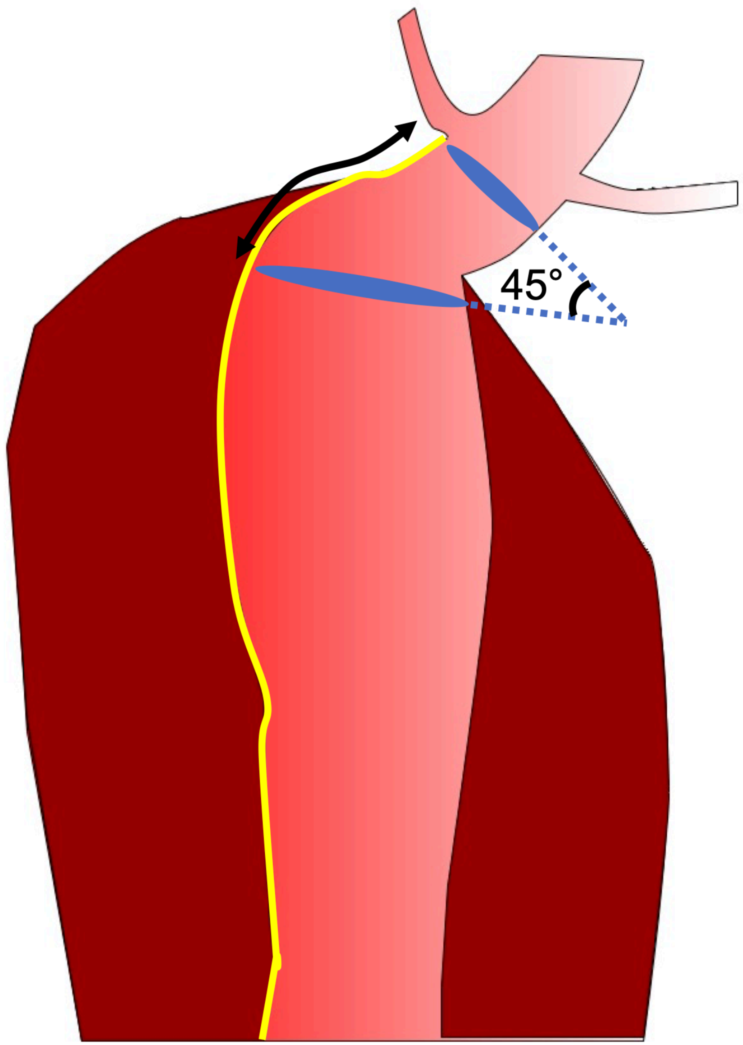


Figure 1 B

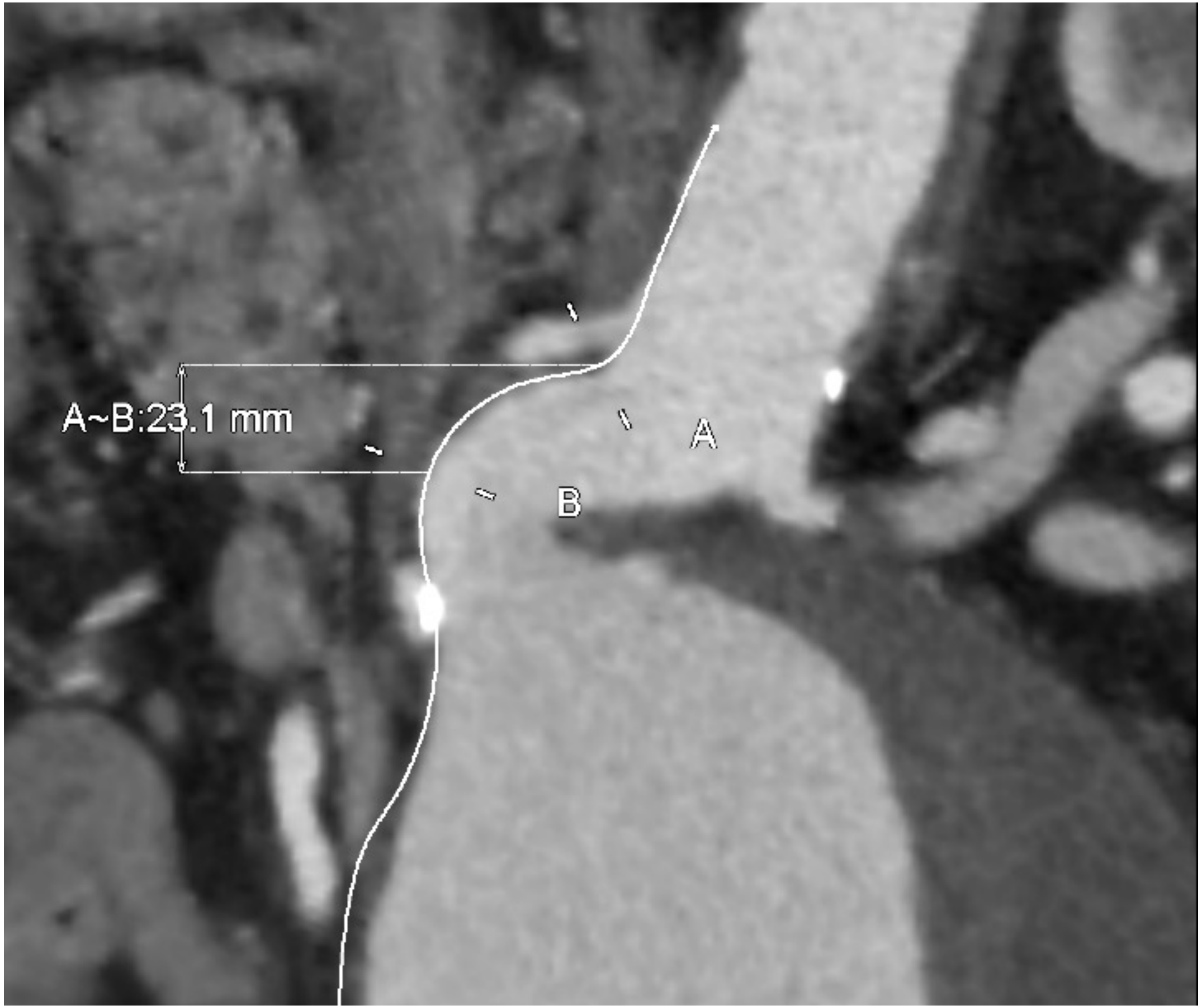


Figure 1 C

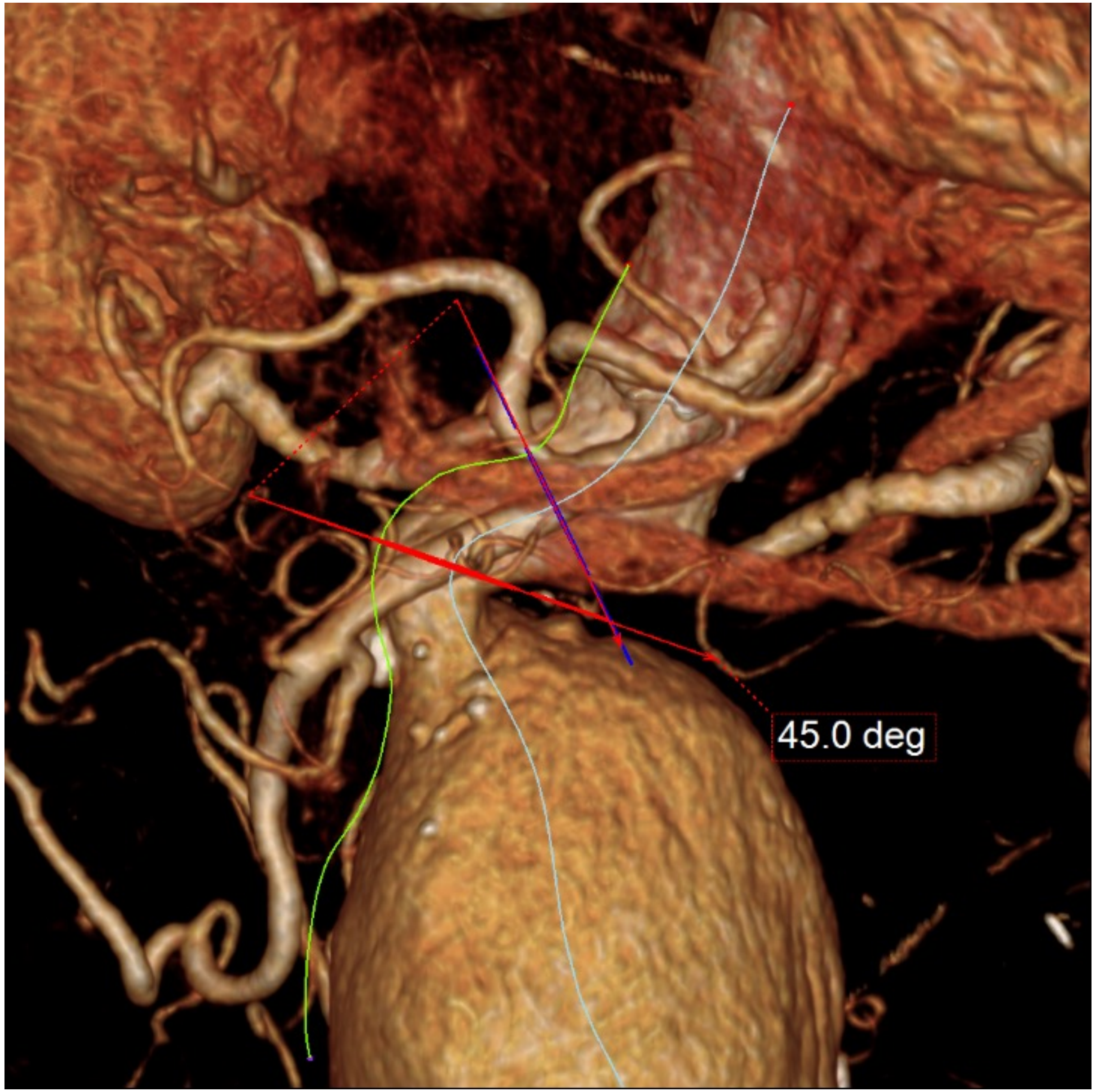


Figure 1 D

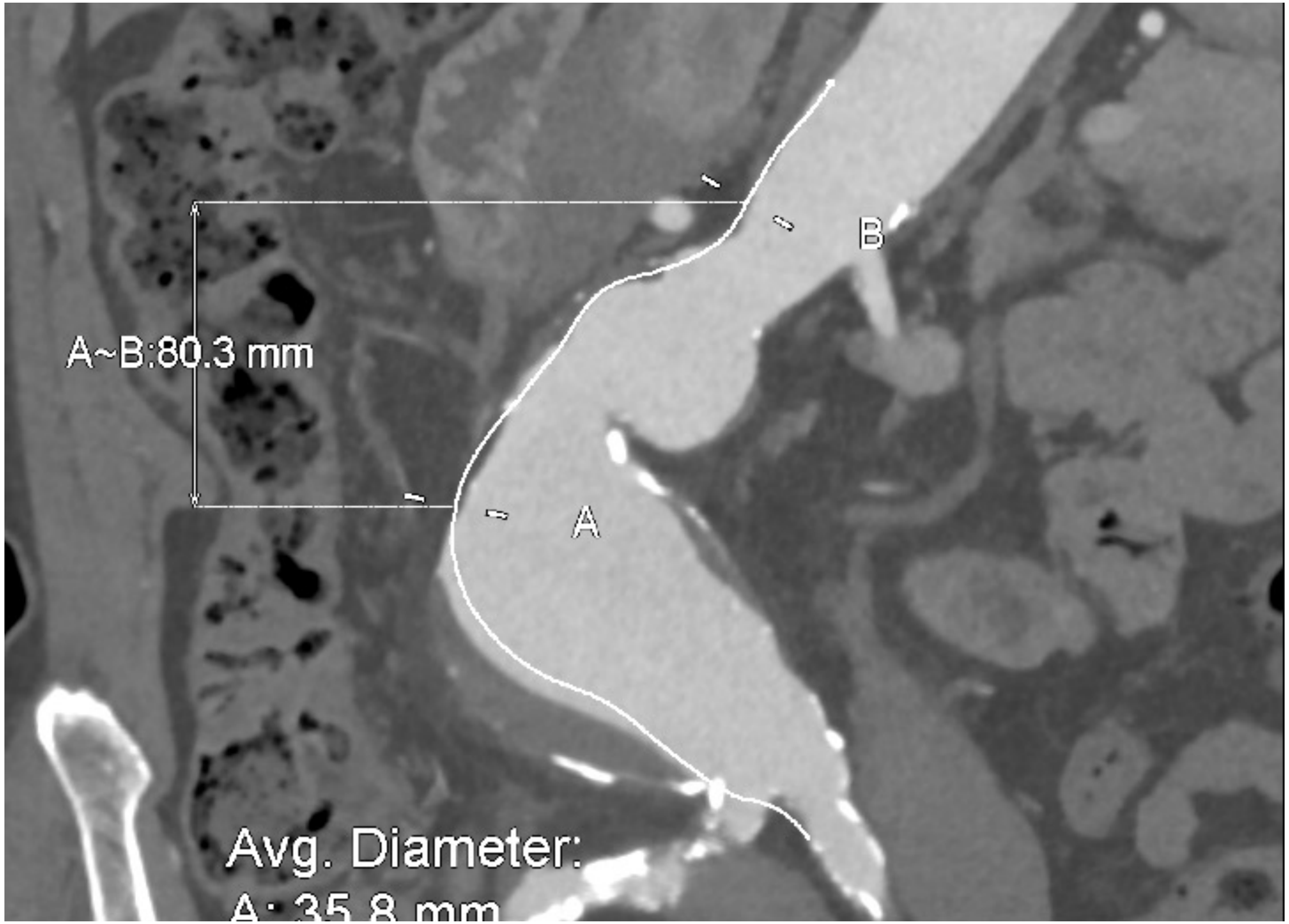


Figure 1 E

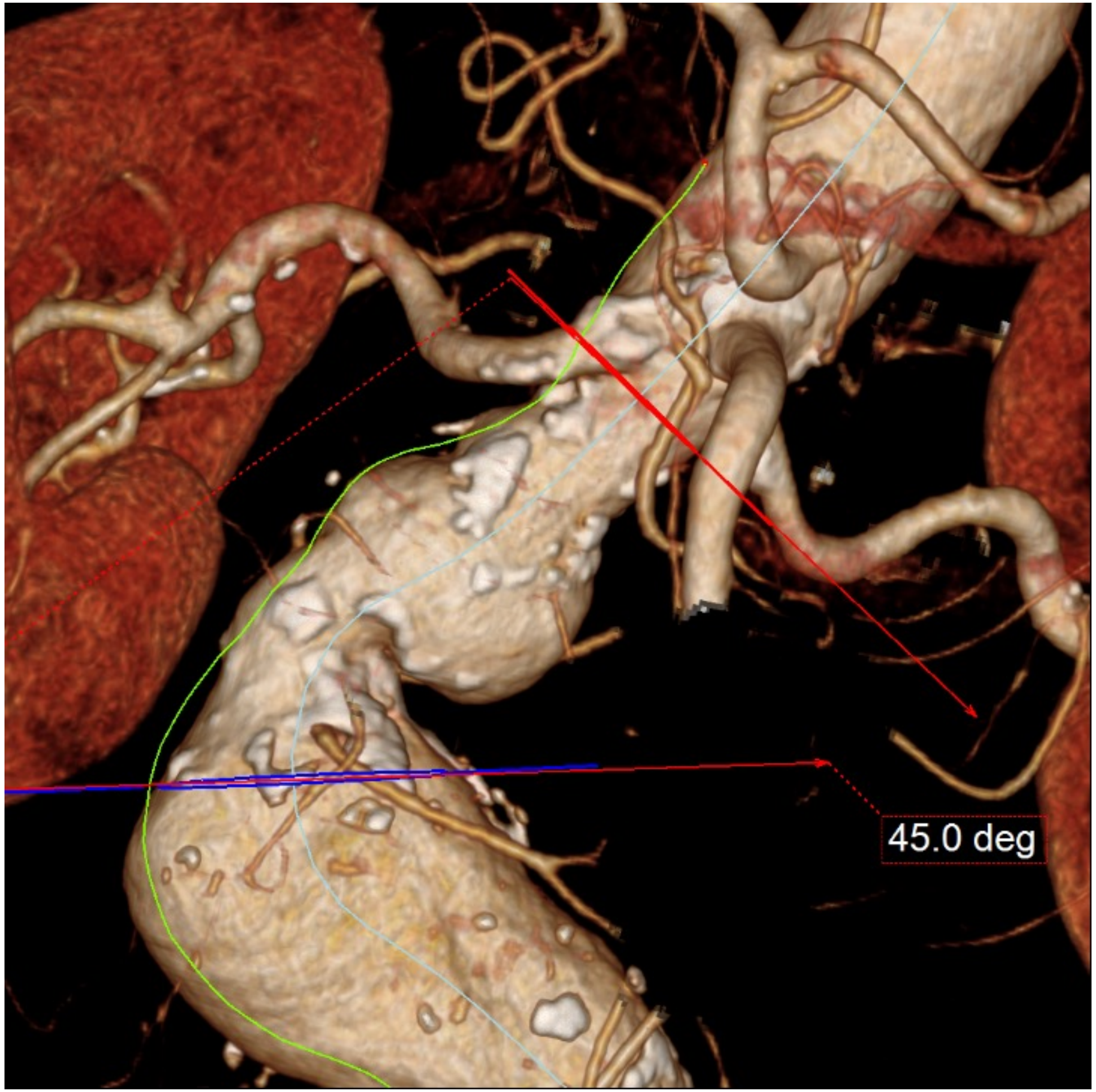
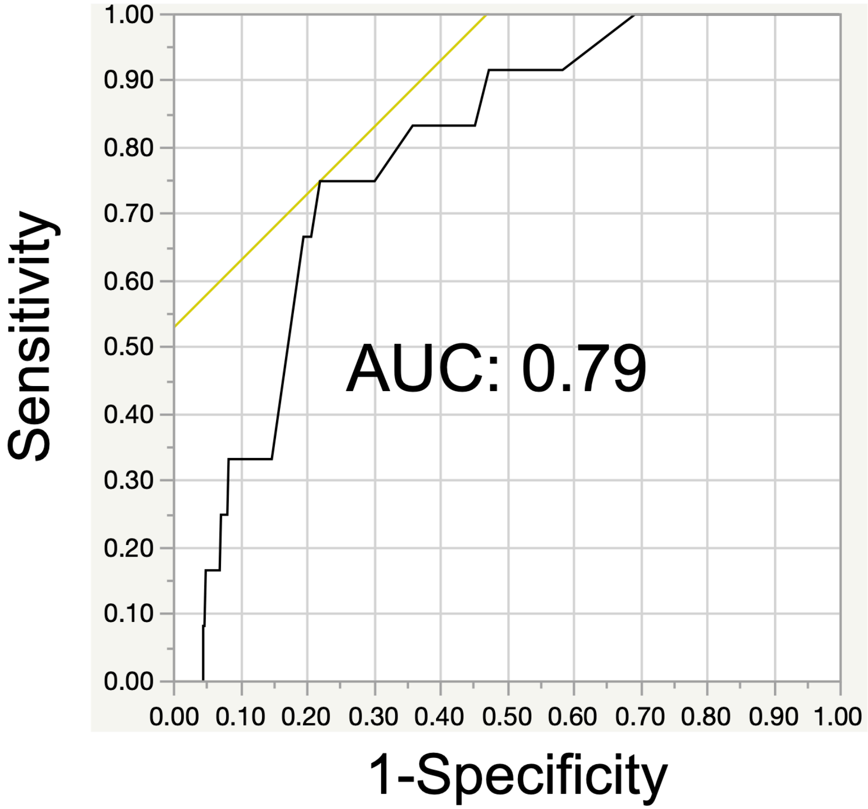
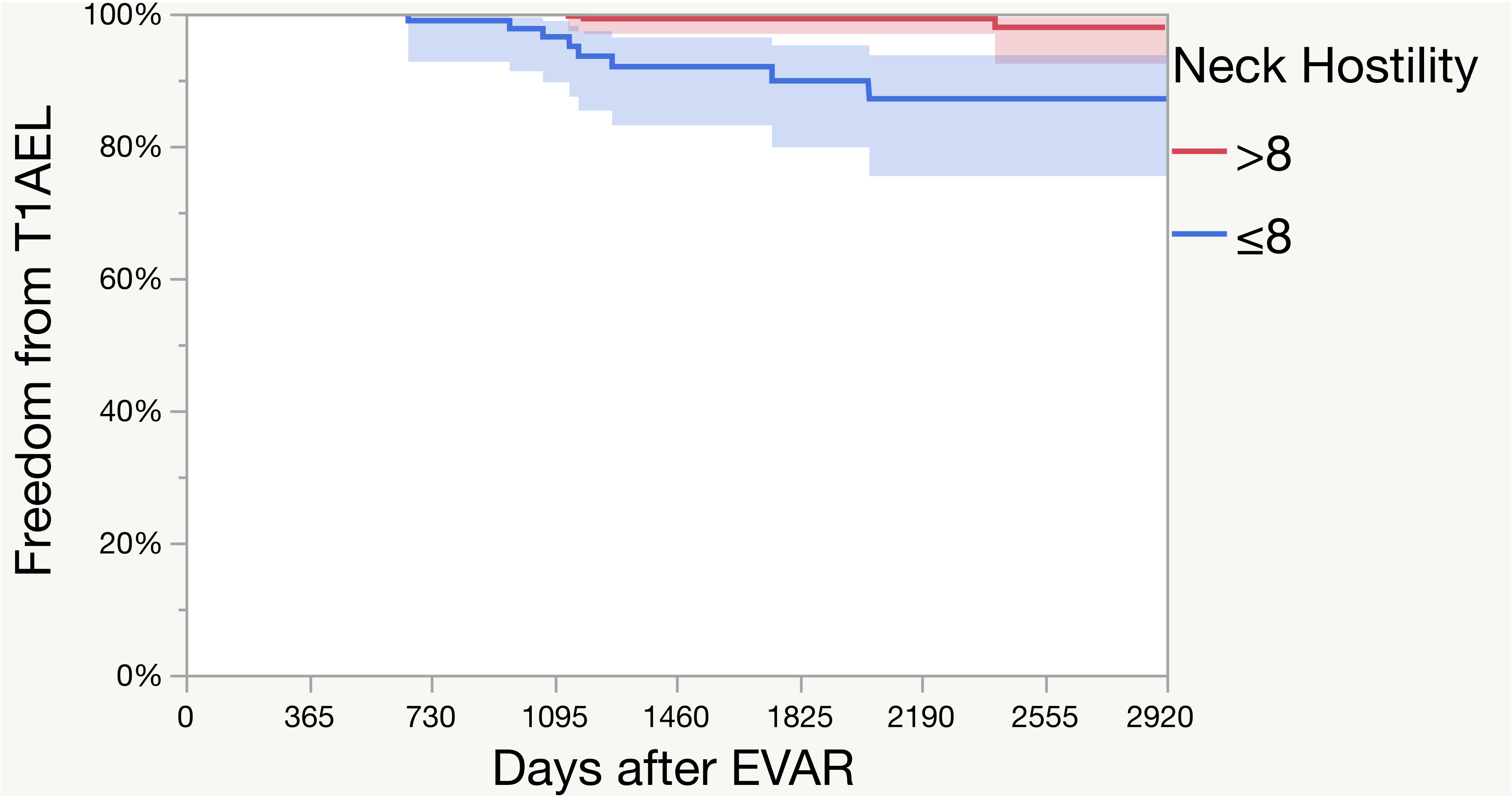


Figure 2



1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Sensitivity
AUC: 0.79
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00
1-Specificity

Figure 3



No. at risks

Neck hostility >8	413	369	325	281	224	168	107	69	49
Neck hostility ≤8	124	108	88	76	52	43	29	22	17