Endograft Limb Occlusion in EVAR: Iliac Tortuosity Quantified by Three Different Indices on the Basis of Preoperative CTA


Objective: To assess the incidence and outcome of graft limb occlusions after endovascular aortic repair (EVAR) of abdominal aortic aneurysm (AAA) in a high volume single centre. To quantify iliac artery tortuosity in patients with AAA and correlate this with limb occlusion.

Design: Data were collected consecutively and prospectively, and analyzed retrospectively.

Materials: Patients treated with Zenith bifurcated stent grafts from January 2000 to December 2010 at a tertiary referral vascular unit were analyzed. Routine regular office follow-up with computed tomography angiography (CTA) and, subsequently, duplex ultrasound imaging was performed. Patients with limb occlusions were identified. For each index patient, two controls were obtained, one immediately preceding and one following the index patient in the consecutive cohort of EVAR patients.

Methods: Demographics and CTA data on limb graft occlusions were recorded and compared with a defined control group. Three different indices were used to describe the tortuosity of the iliac vessels based on preoperative CTA: pelvic artery index of tortuosity (PAI), common iliac artery index of tortuosity (CAI), and a visual description of vessel tortuosity — the double iliac sign (DIS). Demographic data and indices were correlated for later occurring limb occlusion.

Results: 504 patients underwent EVAR and 18 patients experienced graft limb occlusion during a median follow-up of 28 months (range 0—133). Primary graft patency was 97% at 1 year and 96% at 3 years. Logistic regression showed that iliac artery tortuosity (DIS) ($p = .001$) and body mass index ($p = .007$) had a significant impact on graft patency.

Conclusion: A tortuous vessel on the preoperative CTA is associated with an increased risk of limb occlusion after EVAR. Adjunctive stenting of iliac segments deemed at risk is suggested, which is achieved without compromise of the aneurysm repair.

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Keywords: Abdominal aortic aneurysm, Endovascular, Limb occlusion, Iliac tortuosity index

INTRODUCTION

Modern image-guided endovascular techniques offers important advantages for patients with abdominal aortic aneurysm (AAA). Endovascular aortic repair (EVAR) is a minimally invasive procedure, and in general means shorter hospital stays compared with open surgery. However, this positive picture is incomplete, as the benefits to patients are accrued only with a considerable re-intervention rate following EVAR.

Femoral and iliac artery access is essential for delivery of EVAR devices. Calcifications and winding narrow vessels may lead to limb occlusion, which requires additional intervention. Strategies for minimizing the risk of stent graft limb occlusions are extremely important and necessary. Adjunctive selective primary stenting reduces the risk of limb occlusions. Several variables, among others young...
was evaluated according to main body side that the main body of the stent graft was inserted or on the same side that the iliac tortuosity indices. The control group following those with limb occlusions, served as controls for Consecutive EVAR patients, immediately preceding and Control patients were prescribed the lifelong antiplatelet medication, acetylsalicylic acid 75 mg daily.

Postoperative surveillance and follow-up

The EVAR follow-up protocol included image surveillance at 3 months, 12 months, and annually after that. The standard follow up protocol included CTA and plain abdominal X-ray with a physical exam. From 2010 the number of CTA controls has been reduced and replaced by ultrasound examinations. It was noted whether the occlusion occurred on the same side that the main body of the stent graft was inserted or on the opposite side. All follow-up materials were checked, by two investigators, to identify the tentative reason for graft limb occlusion. Occlusion was noted as: 1: compression of the graft limb, 2: kinking of the graft limb, and 3: other.

Patients were prescribed the lifelong antiplatelet medication, acetylsalicylic acid 75 mg daily.

Control patients

Consecutive EVAR patients, immediately preceding and following those with limb occlusions, served as controls for the analysis of the iliac tortuosity indices. The control group was evaluated according to main body side — same side occlusions were paired up with two same side controls and vice versa.

METHODS

EVAR preoperative imaging

Biphasic CTA acquisition (unenhanced and contrast-enhanced with bolus tracking), including the deep femoral arteries, was performed on all patients. CTA scans were sent to a dedicated 3D-computer (Vitrea, version 6.0.1282.6267, Vital Images, Minnetonka, MN, USA) for post processing and center-lumen-line evaluations. Measurements were determined from outer to outer circumferential wall in any direction using a Picture Archive Computer System (PACS) system (Agfa Impax 5.2, Agfa-Gevaert NV, Mortsel, Belgium). Only patients with CTA scans, which enabled the dedicated 3D workstation to create center-lumen-line reconstructions of good quality, were included in the study.

Iliac artery tortuosity indices

Based on the preoperative CTA, the relevant iliac artery of each patient was classified retrospectively according to the following three tortuosity indices:

1. Pelvic artery index of tortuosity (PAI): The length of the pelvic artery (based on center-lumen-line) from the aortic bifurcation down to the origin of the common femoral artery divided by the length of the shortest distance between the two landmarks (Fig. 1).

2. The common iliac artery index of tortuosity (CAI): The length of the common iliac artery (based on center-lumen-line) from the aortic bifurcation to the origin of the internal iliac artery divided by a straight line between the two landmarks (Fig. 1).

3. Double iliac sign (DIS): Whenever parts of the iliac vessel (within the landing zone of the graft limb) were visually doubled or more on an axial CTA-slice, an angulation of >90° was depicted as a sign of severe tortuosity. The DIS was recorded as present or not present, but no other quantitative measurements were taken (Fig. 1).

Semiautomatic center-lumen-line measures were applied when feasible, otherwise a multiplanar reconstruction technique was used in the rest of the scans. Manual adjustment was performed for best fit of center-lumen-line. Straight lines were measured on the 3D workstation in the axial plane and when needed, adjustments were supported in orthogonal planes.

CTA analysis included distal aortic diameter, landing zone diameter and region, namely common or external iliac artery, as well as notes on the introduction site of the main body system. CTA diameter measurements of the distal aorta were determined from inner wall to inner wall, the rest of the CTA diameter measurements were determined from outer wall to outer wall of the vessels.

EVAR procedure

Procedures were performed in an angio-suite/hybrid-suite with the patient under general anesthesia (the institutional standard protocol). All patients were systemically heparinized (50 IE heparin/kg body weight) and given intraoperative antibiotic prophylaxis. Depending on anatomy, deployment of the endovascular stent graft was performed with limbs in either the common or external iliac artery (when needed after coiling procedures). Finally all stiff guide-wires were removed and a completion angiogram was performed to assess technical and clinical success.
When luminal compression was suspected, and confirmed by angiogram, a self-expandable bare metal nitinol stent was implanted. Indications for adjunctive primary stenting were retrospectively reviewed on the completion angiogram and noted as 1: compression in graft, 2: compression in the overlap zone of the graft and native vessel, and 3: compression of the peripheral native vessel. All patients with adjunctive primary stenting were also analyzed for their iliac tortuosity indices.

**STATISTICS**

Mean and standard deviation (SD) was used to summarize continuous variables with symmetric distribution, and median and range were used for non-symmetric distributions. Number and percentages were used for categorical variables. Descriptive statistic and logistic regression analysis were used for risk assessment of the demographic data. Logistic regression analysis was used to assess the different indices and their relation to limb occlusions. To describe patency a Kaplan-Meier analysis was performed. All statistical calculations were performed using IBM SPSS Statistics 20 software (SPSS Inc, Chicago, IL, USA). Survival function was printed in GraphPad Prism 5.0 software (GraphPad Software, San Diego, CA, USA).

**RESULTS**

During the 11 year period, 2000 through 2010, 504 patients (451 men) with mean age 73 years (range 48–90) were electively treated for AAA with a bifurcated Zenith stent graft. Twenty patients were lost to follow-up. All-cause mortality during follow-up was 8% (n = 37) at 1 year, 14% (n = 61) at 2 years, and 22% at 3 years (n = 84). Limb occlusion occurred in 18 patients (3.6%) and 20 limbs (2%) during a median follow-up of 28 months (range 0–133).

Three of these 18 patients were found when crosschecking with the national registries. Primary graft limb patency was 98% at 3 months, 97% at 12 months, and 96% at 36 months (Fig. 2). One patient was excluded from further analysis because of a missing preoperative CT scan as images are not stored in the hospital PACS after 10 years. Two patients

![Figure 1. Figures of indices as shown on (A) drawing and (B) axial computed tomography image at the level of sacroiliac joints. Pelvic artery index of tortuosity (PAI): PAI = length of 1/length of A. The starting point was defined as the point on the central lumen line, where the perpendicular crossed the bifurcation. The endpoint, the origin of the common femoral artery was defined as the point on the center-lumen-line, where the perpendicular line crosses the takeoff of the inferior epigastric artery. The common iliac artery index of tortuosity (CAI): CAI = length of 2/length of B. The starting point was defined as with PAI. The endpoint was defined as the point on center-lumen-line, where the perpendicular line crosses the takeoff of the internal iliac artery. Double iliac sign (DIS) (white arrows on (B)): whenever a part of the iliac vessel (within the landing zone of the graft limb) was visually doubled or more on an axial CTA slice, an angulation of >90° was depicted as a sign of severe tortuosity. DIS was recorded as present or not present, but no other quantitative measurements were taken.

![Figure 2. Kaplan–Meier plot shows the cumulative rate of freedom from occlusion.](image-url)
experienced bilateral occlusion but they were counted only once corresponding to the occlusion that occurred first. Thus, 17 patients with 17 graft limb occlusions were analyzed further and compared with 34 patients/graft limbs in the defined group of control patients.

The presenting symptoms were acute ischemia in nine (53%) diagnosed within hours of the initial symptoms. Another six (35%) patients experienced claudication, first diagnosed during regular follow-up. Two were unaccounted for. The limb occlusions were treated surgically in nine (53%) (eight cross-over bypasses and one axillo-bifemoral bypass), endovascularly in three (18%), combined procedures in three (18%), and conservatively in two (12%). One patient with an acute total graft occlusion, 17 months after EVAR treatment, had a transfemoral amputation performed after a failed attempt at revascularization followed by an early death 2 days later as a result of multiple organ failure. In the follow-up period, there were two cases of re-limb occlusion, occurring 1 and 4 months after primary combined and endovascular procedures, respectively. The first was handled with a cross-over bypass, the other with an additional bare metal stent.

No significant difference was shown between patients with graft occlusion and patients with patent grafts \((n = 486)\), except for body mass index (BMI) \((p = .045)\). This was confirmed by a stepwise logistic regression analysis with backward elimination (Table 1).

Using the three iliac tortuosity indices, the 17 occluded limbs were compared with the 34 control limbs regarding the potential for the indices to predict graft limb occlusion (Table 2). CAI, but not PAI, was significantly more often in the occluded limbs \((p = .003)\). Likewise the double iliac sign (DIS) was noticed significantly more often in the occluded limbs \((p = .009)\).

Looking at other parameters of potential predictive value for graft limb occlusion extension of the graft limb into EIA was more common in graft limbs that subsequently occluded \((p = .03)\). The diameters of the AAA, the distal aorta, the landing zone, and the limb of the stent, and the state of runoff, in terms of superficial femoral artery occlusion, did not differ significantly (Table 2).

BMI >30, hypertension, tortuosity (expressed by DIS), and landing zones were analyzed in a logistic regression format, and only BMI >30 and DIS remained significant \((p = .007\) and \(p = .001\), respectively).

To identify the cause of occlusion all follow-up examinations were re-analyzed. Kinking of the graft limb was found in 10 (59%) cases and compression in four (24%). In the remaining three patients, no obvious mechanical or technical reason could be identified. These three patients did not have DIS and all limbs were landed in CIA, but they had BMIs of 32, 29, and 35, respectively.

Primary adjunctive bare stents (SMART stent, CORDIS, Johnson & Johnson, USA) were used in 61 limbs (6%) in 58 (12%) of the total 504 patients. None of the stented graft limbs developed occlusion during the follow-up period \((p = .34)\). The occurrence of tortuosity and the site of the distal landing zone of these patients were comparable to those found in the occluded graft limbs, that is 29 (48%) had DIS and in 16 (26%) patients the landing zone was extended to the EIA, but differed significantly from those found in the control limbs \((p = .01\) and \(p = .03\), respectively). The indication for the primary adjunctive stenting procedure is given in Table 3, and the status of the 17 occluded and 34 control graft limbs is listed for comparison. Only 10% of graft limbs that eventually occluded (2 of 17) or served as control limbs (3 of 34) revealed features that led to primary stenting.

**DISCUSSION**

Limb occlusion is a severe complication after EVAR. There are a number of different stent grafts commercially available; they differ with regards to graft material (polyethylene terephthalate, PET [Zenith, Endurant] or

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<th>Table 1. Multivariate regression analysis of baseline characteristics of patients associated with limb occlusion.</th>
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\(a\) Comparing control patients and patients with limb graft occlusion.

\(b\) Sum <\(n\) because of missing values.

\(c\) Current or history of smoking.

\(d\) Cardiac and pulmonary morbidity defines all treatment required conditions.

\(e\) Reference 13.
The following measurements were also analyzed for the total cohort: landing zone at EIA (9.5%, p = .02), AAA diameter (65 ± 11 mm, p = NS), diameter at landing zone (15 ± 4 mm, p = NS) and stent graft limb diameter (18 ± 4 mm, p = NS). EIA = External iliac artery, AAA = Abdominal Aortic Aneurysm, SFA = Superficial Femoral Artery.

The present study demonstrates a significantly higher occlusion rate in obese patients and in patients with tortuous iliac vessels. Quantification of the iliac tortuosity was attempted using three different indices. Both CAI and the direct visual sign, DIS, correlate with the adverse event of limb occlusions, but DIS is much simpler to generate. Their preoperative CTA assessment included an individual evaluation of the tortuosity of CIA and/or stenosis of the native CIA. Of 33 stented limbs, 15 were inserted based on the preoperative CTA alone. With this approach limb occlusion was eliminated in their series of patients. Several other and more time consuming methods of describing the tortuosity of iliac vessels have been published, but none have been compared with limb occlusion.

Patients with limb graft occlusion (n = 17) Control patients (n = 34) p
Pelvic artery index of tortuosity (PAI) Mean (SD) 1.61 (0.3) 1.48 (0.25) NS
Common iliac artery index of tortuosity (CAI) Mean (SD) 1.31 (0.2) 1.16 (0.13) .009
Double iliac sign (DIS) Yes 9 (53%) 4 (12%) .003
Landing zone EIA 5 (29%) 2 (6%) .03
AAA diameter (mm) Mean (SD) 65.1 (21.5) 63.7 (8.5) NS
Diameter of iliac artery at landing zone (mm) Mean (SD) 14.4 (3.2) 14.1 (2.9) NS
Stent graft limb diameter (mm) Mean (SD) 16.7 (3.3) 16.8 (3.9) NS
Distal aortic diameter (mm) Mean SD 31.1 (16.2) 27.6 (8.1) NS
SFA occlusion 1 (6%) 2 (6%) NS

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4 In one patient with graft occlusion, the preoperative CT scan was only recorded down to the external iliac artery and therefore, only DIS and the index of CAI could be determined.
5 Four patients had a narrow distal aortic diameter (<18 mm) and three subsequently occluded as a result of compression, while two in the control group with a narrow distal aortic diameter stayed open (p = .065).
6 Additionally, one patient developed SFA occlusion after EVAR.

Table 2. Risk factor analysis of factors associated with graft limb occlusion.
The majority \((n = 14, 83\%)\) of the limb occlusions in this cohort occurred because of mechanical issues. The rest \((n = 3)\) of the occlusions still had a non-compressed endograft at the time of occlusion suggesting thrombogenic events.

The majority of the primary adjunctive stents were placed in the overlap zone between graft limb and native vessel. It was found, in line with others,\(^4,5,10\) that the completion angiogram is inadequate for determining limbs at risk for occlusion. As with the present set of patients, Sivamurthy et al.\(^5\) only experienced limb occlusion in their non-stented patients. Conway et al.\(^22\) did not find any benefit from additional stenting. Amesur et al.\(^6\) found limb occlusions to be eliminated with Wallstent placement in intraoperative IVUS detected stenosis. Primary additional stenting is well accepted as a tool to prevent limb occlusion, but it has not been documented in randomized controlled trials.

The completion angiogram to find high-risk limbs is inadequate and additional IVUS requires extra time and additional expense. Therefore, in line with Oshin et al.,\(^10\) a more liberal use of primary adjunctive stenting in patients whose preoperative CTA reveals signs of severe tortuosity is suggested. An automated vessel description of maximum tortuosity using modern software in a 3-D workstation could be a tool for the future, as it would automatically display the maximum tortuosity when segmenting required vessels for planning EVAR.

**Limitations of the study**

The retrospective design of this study is one limitation. Some patients with occlusions may have been missed, especially those only developing mild or no symptoms. The control patients were chosen in the described way in order to limit bias. The total cohort would have been the most desirable control group. However, this was not possible as the PACS archive deleted data after 10 years. Any matching procedure is an approximation with all its limitations. By selecting the patient that preceded and followed the index procedure, at least a temporal matched control group was obtained.

**Conclusion**

Limb occlusion after EVAR is a potential life-threatening complication and care must be taken to avoid it. A high CAI and the presence of the less time-consuming DIS increases the risk of limb occlusion over time. Besides this, obesity is a risk factor. The authors suggest a dedicated focus on the preoperative CTA, especially the angulations and tortuosity of pelvic arteries followed by scrutinizing the completion angiogram and supplementing the limbs with additional stents in patients to risk.

**FUNDING**

None.

**CONFLICT OF INTEREST**

None.

**ACKNOWLEDGMENTS**

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**REFERENCES**


