# Tips and techniques for optimal stent graft placement in angulated aneurysm necks

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**An increasing number of patients with severely angulated abdominal aortic aneurysm (AAA) necks are being treated by endovascular aneurysm repair (EVAR). Optimal preprocedural planning and investigation of the AAA morphology is essential to achieve a successful EVAR in these patients. In this article, we discuss specific problems that can be encountered during preoperative planning in relation to periprocedural stent graft deployment in patients with angulated AAA necks and offer potential solutions for these problems. (J Vasc Surg 2010;52:1081-6.)**

The proximal aneurysm neck is considered the Achilles' heel of the endovascular aneurysm repair (EVAR) procedure.[1] The length, diameter, and angulation are regarded as important morphologic features of the proximal aneurysm neck,[2,3] and more hostile aneurysm necks are related to adverse EVAR outcomes.[2,4-6] However, with the introduction of newer stent grafts and with increasing experience in the use of endovascular devices, patients with shorter, more severely angulated and wider aneurysm necks are also considered eligible for EVAR.[7]

Angulation of the proximal aortic aneurysm neck makes adequate proximal stent graft fixation and sealing more difficult. For an optimal position of the stent graft body, it is important that adequate planning has been performed. Preprocedural computed tomography angiography (CTA) measurements, the choice of stent graft size, and the plan for deployment are all heavily influenced by the angulation of the aneurysm neck.

The purpose of this article is to draw attention to the specific preoperative preparation for EVAR in patients with angulated abdominal aortic aneurysm (AAA) necks. Problems that can be encountered during preoperative planning and stent graft deployment in patients with angulated AAA necks are discussed, and potential solutions for these problems are given.

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## MEASUREMENTS AND PLANNING

In patients with angulated AAA necks, a CTA must be obtained preoperatively for adequate planning of the EVAR procedure, although magnetic resonance angiography (MRA) can also be used. The morphology of the access vessels, the aneurysm, and the proximal and distal stent graft landing zones must be examined with the use of these imaging techniques.

**Aortic center lumen line.** An aortic center lumen line (CLL) of the aorta should be constructed with the use of dedicated software. A reconstructed stretch view of the aorta can thereafter be generated around this CLL. This stretch view allows for optimal diameter measurements perpendicular to the CLL and length measurements alongside this CLL. The angulations in the proximal aortic aneurysm neck must also be quantified with the use of a volumetric 3-dimensional reconstruction of the aorta, according to an earlier published protocol.[8]

**Investigation of the aneurysm neck.** Patients with angulated aneurysm necks are more likely to have additional adverse morphologic neck features than other AAA patients.[9] The aneurysm neck should therefore be investigated for its shape, length, and diameter as well as for the presence of thrombus, calcification, and bulging.

The investigation of the AAA neck length is a complicated part of this process. While measuring the aneurysm neck length on a reconstructed view along the CLL, one should realize that the length of a virtually stretched aneurysm neck is being measured. The actual aneurysm neck length is most likely not equal to the *functional* neck length in patients with angulated necks. The *functional* neck is

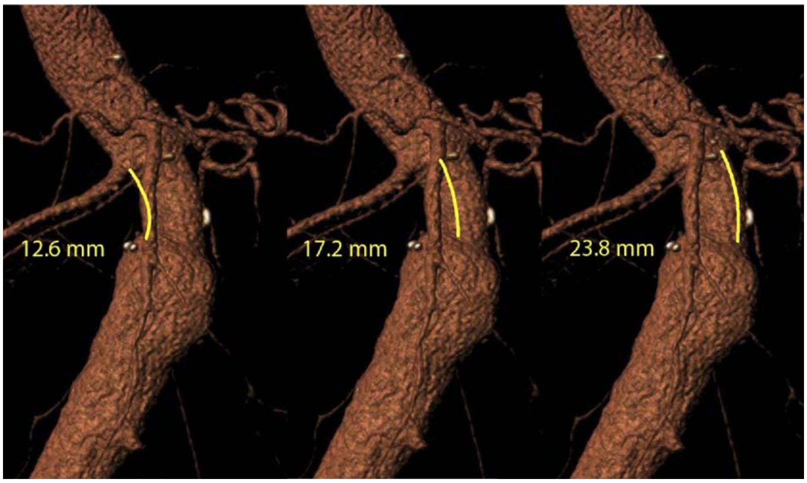


**Fig 1.** The *yellow lines* in the aneurysm neck are lumen lines. The center lumen line is projected in the middle, a lumen line in the inner curvature of the aneurysm neck is on the right, and a lumen line in the outer curvature of the neck is on the left. The center lumen line length indicates the true length of the neck, but will probably not be the functional neck.

defined as the length of the neck that can be adequately used for fixation and sealing of the stent graft. Angulation in an aneurysm neck, however, hampers the effort to use the entire neck for stent graft fixation and sealing.

An inner and outer curvature exists in an angulated aneurysm neck, with the shorter inner curvature probably being the limit of the functional neck (Fig 1). A stent graft can only use the entire length of the neck for fixation and sealing if the aneurysm neck is straightened. Periprocedural straightening of an aneurysm neck thus increases the functional neck, which is therefore desirable.

It is important to estimate the straightening possibilities during the procedure because this may optimize the sealing zone for the stent graft and also possibly influences the stent graft sizing process. Whether the aneurysm will straighten during EVAR depends on many factors, however, and is therefore hard to predict.

One factor is the patient's anatomy. Calcification of the aneurysm neck, the length of the neck, the presence and morphology of lumbar arteries in the AAA neck, and the angle between the neck and the common iliac arteries all determine the possibility of straightening the aneurysm. Another important factor is the stiffness of the guidewire introduced during the procedure. A stiff wire is more likely than a less stiff wire to straighten the tortuosity of the access vessels and the AAA neck.

The length of an aneurysm neck probably is the most important anatomic factor determining the straightening possibilities during the procedure. A guidewire in a long aneurysm neck is forced to follow the track of the aneurysm neck and take the inner-outer curvature route. In a short aneurysm neck, however, the guidewire will take the inner-inner curvature route, which is almost straight; therefore, the longer the angulated aneurysm neck, the more it can be straightened during the procedure.

**Stent graft sizing.** The instructions for use of most stent grafts recommend oversizing the body of a stent graft 10% to 20% compared with the preoperative aortic neck diameter. These recommendations are based on straight aneurysm necks and thus symmetric placement of the stent graft.

In an angulated aneurysm neck, however, the stent graft size needs to be determined after the investigation of the morphology of the neck and the estimation of the periprocedural angulation. It is important to realize that there is a possibility that a stent graft can be positioned asymmetrically in an angulated aneurysm neck. This asymmetric deployment can occur because of the asymmetric positioning of a guidewire in an angulated aneurysm neck, which is caused by the curves in the neck and the stiffness of the wire and the delivery system.

The differences between symmetric and asymmetric positioning are shown in Figs 2 and 3. The following explanation describes the possible consequences of asymmetric positioning on stent graft sizing by giving a simple example:

Imagine a patient with an aneurysm neck diameter of 25 mm (circumference, 78.5 mm). A symmetrically placed stent graft with a diameter of 30 mm would fit perfectly in this aneurysm neck (20% oversizing). If this stent graft is not placed symmetrically, but at an angle of 20° to the aneurysm neck, the oversizing will be less. The area that has to be covered by the stent graft will be elliptically shaped and more aortic wall will have to be covered. In this situation, the circumference of the ellipses will be 81.2 mm, which corresponds to a circle with a diameter of 25.8 mm, and the oversizing will be 16% instead of 20%. If the stent graft is placed at an angle of 40% to the aneurysm neck, which is not uncommon in severely angulated necks, then the circumference of the ellipse of the neck increases to 92.0 mm, which

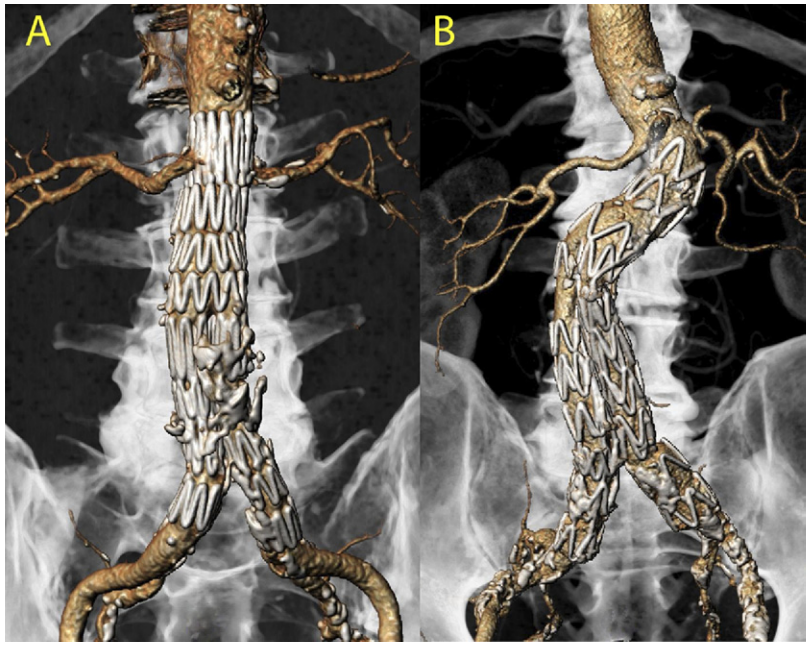


**Fig 2. A,** A symmetrically deployed stent graft is shown in a straight aneurysm neck. **B,** An example of an asymmetrically positioned stent graft is shown in an angulated aneurysm neck.


**Fig 3.** This is an enlargement of the aneurysm neck that is shown in Fig 2, *B*. The stent graft is placed asymmetrically compared with the aneurysm neck. The asymmetric placement of stent grafts may have serious consequences.

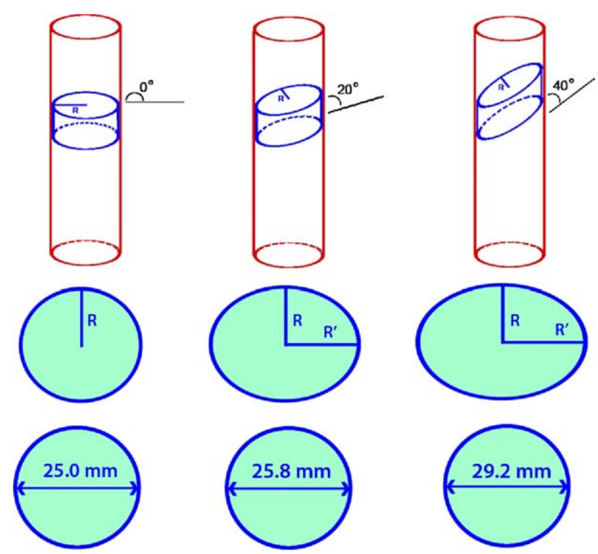


**Fig 4.** Drawings show the consequences of asymmetric stent graft placement. The radius/diameter of a plane not perpendicular to aorta increases the more oblique it is placed to the perpendicular plane, thereby influencing the degree of oversizing.

resembles a circle with a diameter of approximately 29.2 mm (circumference, 92.0 mm). In this situation, a stent graft of 30 mm is only oversized 2.4% (Fig 4).

We therefore believe that stent grafts should be oversized >20% (based on diameter measurements perpendicular to the aorta) if asymmetric placement can be expected. Because the appropriate diameter of a stent graft depends on the preprocedural straightening of an aneurysm neck and the position of a guidewire in the neck, stent grafts with different proximal diameters should be available during EVAR procedures in angulated necks. Furthermore, the interventionalist should anticipate stent graft deployment over very stiff and less stiff guidewires, which may influence the symmetry of the stent graft placement.

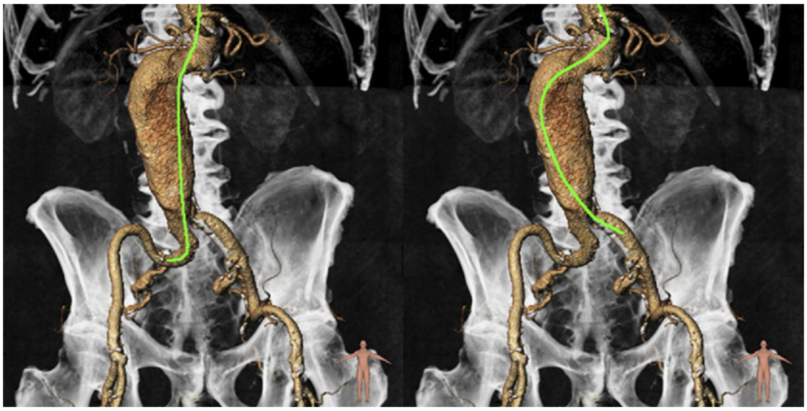

**Fig 5.** The *green lines* are expected guidewire routes. **Left,** A guidewire is introduced in the right groin. **Right,** A guidewire is introduced in the left groin. The access site for the guidewire influences the route of the guidewire.

**Access site determination.** Once stent graft sizes are determined, the preferable access site for the main device is chosen. This, apparently, depends on the diameter and calcification of the access vessels and on the morphologic characteristics of the AAA neck. The angulation of the iliac vessels should not be forgotten, however. The tortuosity of the iliac vessels, and especially the aortoiliac angle, influences the direction of the guidewire and, thus, of the stent graft. The straightening of the aneurysm neck, which determines the length of the functional neck, and the final track of the guidewire, which determines whether the stent graft can be deployed in line with the aorta or asymmetrically, are therefore also dependent on the access site for the main device (Fig 5). Therefore, the interventionalist should anticipate the introduction of the stent graft from either groins when planning the procedure.

**C-arm positioning.** Another important aspect of preoperative planning is the determination of the most optimal C-arm position, with a view perfectly perpendicular to the origin of the lowermost renal artery. A suboptimally positioned C-arm will cause overlap of vascular structures. By optimally positioning the C-arm, the stent graft can be deployed just below the lowermost renal artery, allowing for maximal sealing and fixation of the stent graft in the aneurysm neck (Figs 6 and 7).

The most optimal C-arm position depends on the clock position of the ostium of the lowermost renal artery and the angulation of the aneurysm neck, which can be determined preoperatively. The C-arm needs to be angulated orthogonally to the aortic neck and orthogonally to the armpit of the most distal renal artery. This most optimal position of the C-arm can be different during the procedure than expected preoperatively, as the aneurysm neck possibly straightens out more or less than expected. We have found that although the angulation of the AAA neck can change perioperatively, the clock position of the renal arteries does not change under the influence of an introduced guidewire or stent graft. Moreover, the most optimal C-arm position can be checked and fine-tuned during the procedure if stent

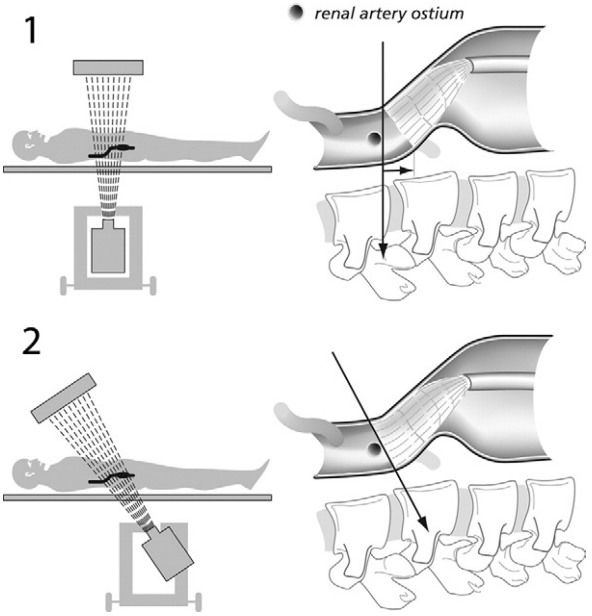


**Fig 6.** Inaccurate positioning of the C-arm underestimates the length of the abdominal aortic aneurysm (AAA) neck. **Panel 1,** A neutral position of the C-arm is shown in the images on the top. Although the stent graft position seems visually right, the stent graft position is suboptimal, and the entire neck is not used for stent graft fixation and sealing. **Panel 2,** A C-arm position orthogonal to the aortic angulation (cranial-caudally angulated) is shown. The entire AAA neck is used.

grafts with more than two markers at the proximal end are used. If a stent graft has more than two proximal markers at one level, then all markers are visible in a straight line in the most optimal C-arm position.

We therefore advise that a stent graft should be introduced under fluoroscopy, with the C-arm in the standard anterior-posterior position, up to the expected location of the lowermost renal artery. The C-arm is thereafter angulated in the preoperatively determined most optimal posi-

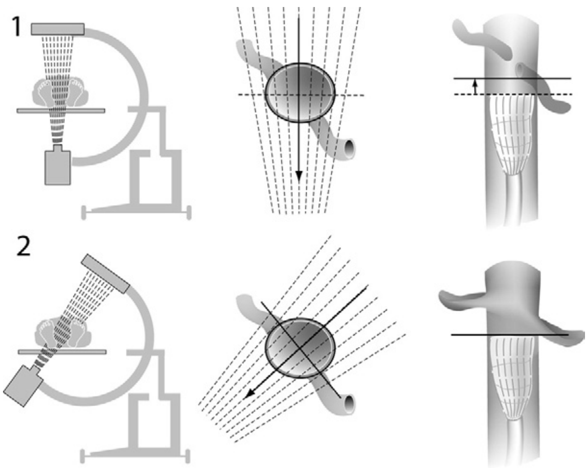


**Fig 7.** Inaccurate positioning of the C-arm underestimates the length of the abdominal aortic aneurysm (AAA) neck. **Panel 1,** A C-arm position in neutral position is shown. Again, the stent graft position seems visually optimal. **Panel 2,** Lateral angulation of the C-arm provides a view orthogonal to the clock position of the renal arteries. This view allows the entire use of the AAA neck for stent graft fixation and sealing.

tion, taking the neck angulation and clock position of the renal arteries into account. Angiography is then performed, and deployment of the stent graft is started at the desired position. After deployment of the proximal stent ring(s), the C-arm position can be corrected in the cranial-caudal direction, if necessary, by using the proximal markers of the stent graft. A new angiogram is thereafter advised for fine-tuning of the stent graft position and full stent graft deployment thereafter.

## DISCUSSION

EVAR is increasingly being used as an alternative for open repair in patients with hostile proximal aneurysm neck anatomy. More patients with a hostile neck are considered suitable for EVAR and exclusion criteria are narrowing.[10] Nonetheless, inferior EVAR outcomes have been reported in patients with severely angulated proximal aneurysm necks.[2,4-6] EVAR is far more complex if the proximal aneurysm neck is angulated, and more stent grafts are deployed at suboptimal positions in these circumstances. If this is acknowledged and the potential obstacles in patients with angulated aneurysm necks are recognized, one can adapt to these. By doing this, the results of EVAR in patients with angulated aneurysm necks can be improved.

The functional neck length and the possibility of enlarging this neck by straightening the aneurysm neck, can be investigated by adequate preoperative investigation and planning. Besides, it can be necessary to adapt the stent graft size (oversize the stent graft >20% based on diameter measurements perpendicular to the aorta) in angulated aneurysm necks. A potential drawback of this oversizing is the possible relationship between oversizing and neck dilatation and stent graft migration. Until now, however, no relation between oversizing and neck dilatation has been confirmed.[11] Moreover, oversizing of up to 25% seems to decrease the risk of proximal endoleaks.[11] We believe that oversizing of stent grafts should be at least 20% in some patients with angulated aneurysm necks.

If asymmetric stent graft placement is considered a possibility, it is advisable to have several stent graft sizes available during the endovascular procedure. The degree of oversizing of the stent graft can be adapted to the straightening of the aneurysm neck, the (asymmetric) position of the guidewire, and the access site of the main device.

Straightening of an angulated aneurysm neck is desirable and can be achieved by the introduction of a very stiff guidewire. However, a stiff guidewire will probably be placed asymmetrically in an angulated neck. To prevent asymmetric deployment, a second stiff guidewire can be introduced for the delivery of the stent graft. If the stent graft introduced over the second guidewire is in an optimal place for deployment, the guidewire over which the stent graft is introduced can be replaced by a less stiff wire. This will result in a more symmetric placement of the stent graft. Nevertheless, one should note that changing a guidewire is not allowed in all stent grafts according to the instructions for use.

In patients with angulated aneurysm necks, it is important for several reasons that most of the aneurysm neck can be used as the functional aneurysm neck: First, the radial forces of a stent graft can only be used for sealing and fixation if it is placed appropriately to the aortic wall. In a more angulated neck, the length of the stent graft alignment to the aneurysm neck will be shorter than in a straight aneurysm neck.

Second, the greater the curvature of a tube, the greater the change in velocity of fluid (blood flow velocity) that circulates in this tube. The force applied against the wall of a tube by a fluid (blood flow) is proportional to the square of the change in velocity in angulated necks, thus resulting in an increased displacement force.[6]

Finally, appropriate positioning, sealing, and fixation are all the more important in patients with an angulated aneurysm neck, because angulated aneurysm necks are related to other adverse anatomic characteristics.[9]

We believe, as was discussed, that appropriate oversizing of stent grafts in patients with angulated aneurysm necks is important. The asymmetric positioning of a stent graft can lead to (intermittent) proximal type I endoleaks or stent graft migration. This problem can be partly overcome by the deployment of a stent graft with suprarenal fixation. Suprarenal fixation diminishes the problem of asymmetric fixation because the angle between the suprarenal and infrarenal aorta is usually smaller than the angle between the infrarenal aorta and the AAA sac. This advantage is particularly present if the proximal bare stent is deployed first (non-bare-stent-captured device), but the fine-tuning of the positioning in these stent grafts is generally considered to be more difficult.

## CONCLUSION

Specific problems come along with the endovascular exclusion of an AAA in a patient with an angulated aneurysm neck. Accurate preoperative measurements, planning, and perioperative attention help to identify, recognize, and adapt to these problems. Doing this can improve the results of EVAR.

## REFERENCES

1. van Herwaarden JA, van de Pavoordt ED, Waasdorp EJ, Albert VJ, Overtoom TT, Kelder JC, et al. Long-term single-center results with AneuRx endografts for endovascular abdominal aortic aneurysm repair. J Endovasc Ther 2007;14:307-17.
2. Boult M, Babidge W, Maddern G, Barnes M, Fitridge R; on behalf of the Audit Reference Group. Predictors of success following endovascular aneurysm repair: mid-term results. Eur J Vasc Endovasc Surg 2006; 31:123-9.
3. Choke E, Munneke G, Morgan R, Belli AM, Loftus I, McFarland R, et al. Outcomes of endovascular abdominal aortic aneurysm repair in patients with hostile neck anatomy. Cardiovasc Intervent Radiol 2006; 29:975-80.
4. Sternbergh WC 3rd, Carter G, York JW, Yoselevitz M, Money SR. Aortic neck angulation predicts adverse outcome with endovascular abdominal aortic aneurysm repair. J Vasc Surg 2002;35:482-6.
5. Hobo R, Kievit J, Leurs LJ, Buth J. Influence of severe infrarenal aortic neck angulation on complications at the proximal neck following endovascular AAA repair: a EUROSTAR study. J Endovasc Ther 2007; 14:1-11.
6. Albertini J, Kalliafas S, Travis S, Yusuf SW, Macierewicz JA, Whitaker SC, et al. Anatomical risk factors for proximal perigraft endoleak and graft migration following endovascular repair of abdominal aortic aneurysms. Eur J Vasc Endovasc Surg 2000;19:308-12.
7. Verhagen HJ, Torsello G, de Vries JP, Cuypers PH, van Herwaarden JA, Florek HJ, et al. Endurant stent-graft system: preliminary report on an innovative treatment for challenging abdominal aortic aneurysm. J Cardiovasc Surg (Torino) 2009;50:153-8.
8. van Keulen JW, Moll FL, Tolenaar JL, Verhagen HJ, van Herwaarden JA. Validation of a new standardized method to measure proximal aneurysm neck angulation. J Vasc Surg 2010;51:821-8.
9. 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;38:657-63.
10. Chisci E, Kristmundsson T, de DG, Resch T, Setacci F, Sonesson B, et al. The AAA with a challenging neck: outcome of open versus endovascular repair with standard and fenestrated stent-grafts. J Endovasc Ther 2009;16:137-46.
11. van Prehn J., Schlosser FJ, Muhs BE, Verhagen HJ, Moll FL, van Herwaarden JA. Oversizing of aortic stent grafts for abdominal aneurysm repair: a systematic review of the benefits and risks. Eur J Vasc Endovasc Surg 2009;38:42-53.

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