Three-Dimensional CT Evaluation for Endovascular Abdominal Aortic Aneurysm Repair. Quantitative Assessment of the Infrarenal Aortic Neck

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Abstract. Endovascular grafting of abdominal aortic aneurysms should be offered only to those patients with suitable anatomy. This is especially true at the level of the proximal aortic neck in order to secure long-term proximal fixation. Aortoiliac anatomy is easy to understand conceptually, however, it is difficult to define and measure quantitatively. In this article, we discuss the use of three dimensional computed tomographic angiography to determine aneurysm morphology and select patients for endovascular repair. Specifically, we apply our methods to define and measure angulation of the aorta and iliac arteries. The anatomic definition of the angulation of the proximal aortic neck is emphasized.

Imaging modalities for operative treatment of abdominal aortic aneurysms

Ultrasonography is the procedure of choice for the initial diagnosis of abdominal aortic aneurysms (AAA) and surveillance of small aneurysms. It is non invasive and inexpensive, uses no radiation, and provides structural detail of vessel wall and atherosclerotic plaque as well as accurate AAA size. However, it is highly technician dependent and image resolution is impaired by body size and presence of intestinal gas.

The gold standard preoperative test for abdominal aortic aneurysm assessment was arteriography up until the early-1980s. Despite issues of cost, discomfort, complications and inaccurate determination of the AAA size, arteriography had a central diagnostic role on operative decision making because it could image: a) the suprarenal extension of the aneurysm, b) concomitant iliac or peripheral aneurysms, c) renal or mesenteric artery disease d) accessory renal arteries and e) lower extremity occlusive disease.

In 1972 computed tomography (CT) was developed as an interactive technique for combining traditional X-ray imaging with computed acquisition and processing of multiple sequential tomographic images. Some years later (1980-90), CT replaced arteriography for the preoperative study of AAs because it was less invasive and more accurate in evaluating AAA size and diagnosing inflammatory, leaking, and ruptured AAs.

Since 1990, helical or spiral CT combined with three dimensional rendering techniques allows for continuous circumferential and longitudinal imaging along the length of the aorta and iliac arteries. Spiral CT with intravenous contrast enhancement (spiral CTA) provides the ideal preoperative imaging for selection of patients for endovascular therapy. Spiral CTA allows for precise diameter measurements of the proximal aortic neck, aneurysm size, and access vessels. Furthermore, path lengths of the proximal aortic neck, renal to aortic bifurcation, and distance to the iliac bifurcation are easily obtained. However, its use can be limited in patients with renal insufficiency.

Three-dimensional reconstruction of spiral CTA images

The image data from a spiral CTA acquired in 1-3 mm thick sections, can be computer processed through software packages to develop three dimensional reconstruction images. These images can be displayed in several different and complementary formats. They are comprehensive and detailed images that allow evaluation of intraluminal blood flow channels, location of branch vessels, and vessel wall characteristics. Reconstruction to any visual angle is possible with satisfactory resolution of arterial branches 1 to 2 mm in size. Each slice of the aortoiliac system can be displayed as well as the axial skeleton of the suprarenal and infrarenal aorta, the aneurysm, the iliac arteries and the renal and mesenteric arteries (2).

To facilitate the measurements of the aortoiliac system for endovascular grafting, the Median Center Line Path (MCLP) is created (3). This is performed through a computerized process. After extraction of the contrast enhanced flow channel from spiral CT angiographic images the software creates orthogonal cross-sections at 1 mm intervals between two limits of calculation which are manually selected by the operator. The center
point for each cross-section is then automatically marked and all these subsequent center points (at 1 mm intervals) are visualized at the display and they compose the Median Center Line Path (Fig. 1). The MCLP provides in a line the aortoiliac tortuosity in a three-dimensional image and can be used as a realistic model of the aortoiliac angulation. With the addition of the orthogonal cross sections we can measure lengths, diameters, angles, cross section areas and volumes of any aortoiliac segment. This technology permits precise measurements based on a three dimensional reconstructed image in contrast to the measurements based on a two dimensional image from a conventional CT or angiography (Fig. 2).

Aortoiliac morphology and patient selection

The endografts that are currently approved for clinical use in the United States and those in clinical trials differ in several design features. Thus, each graft has its own indications for use making some patients eligible for one graft and not for another. However, certain anatomic factors are considered essential for all types of endovascular grafts and should be carefully evaluated and measured before endovascular grafting, independently of the graft specific protocol. It is recognized that the methods used for measuring and describing aortoiliac morphology influence treatment results of endovascular therapy of abdominal aortic aneurysms.

Complete hemodynamic sealing and secure fixation at the graft attachment sites are the absolute requirements for permanent aneurysm exclusion. Therefore, it is necessary to clearly define the anatomic characteristics that are crucial for aneurysm exclusion. The two of the most important factors include: 1) anatomic parameters of the aortic neck and 2) anatomic parameters of the iliac arteries. Evaluation of proximal neck anatomy includes determination of five factors: a) length, b) diameter, c) configuration or shape, d) angulation, e) and presence of atheroma or thrombus within (4). Judgement about the distal fixation zones (iliac arteries) includes determination of three factors: a) measurement of length of a suitable segment (not aneurysmal, without excessive thrombus or atheroma) of the iliac artery to be used as a distal attachment site, b) minimal diameter of the iliac arteries to allow access with the endovascular equipment (sheaths etc), c) and iliac tortuosity. Presence of internal iliac aneurysms is also a significant challenge depending on the acceptance of the risk of occluding one or both internal iliac arteries, or proceeding with an additional surgical treatment of these aneurysms. These anatomic criteria are used to determine whether a patient is a candidate for endovascular grafting and to select the type of the graft to use.

Anatomic parameters of the aortic neck

The proximal aortic neck is defined as the distance from the lower renal artery to the start of the aneurysm (Fig. 3). In our series of patients with the AneuRx stent graft (Medtronic, Santa Rosa, CA) a neck length of at least 10 mm was required. The aortic neck was defined on the three-dimensional image as the segment between two points of the MCLP of the aorta. These two points (orifice of the lower renal artery and start of the aneurysm) are defined by scrolling on the computed CTA images and clicking on the anatomic points. The point of the orifice of the lower renal is visually detected and manually selected by the vascular surgeon who does the evaluation. Although the start of the aneurysm
The proximal to the aneurysm aortic segment is an aneurysm. This patient has no aortic neck (he has a juxtarenal aortic aneurysm).

is generally considered to be defined easily, the precise anatomic definition of this point is dependent considerably on the operator. The point at which the aorta starts to be an aneurysm is also manually selected by the operator (Fig. 4).

**Neck Length**: The measurement of the length of the proximal fixation zone is calculated between the point of the MCLP at the orifice of the lower renal artery and the point of the MCLP at the start of the aneurysm.

**Neck diameter**: The diameter of the neck is measured on the orthogonal cross sections of the neck, from the outer wall to the outer wall. Orthogonal cross sections of the neck can be obtained at 1 mm intervals along the length of the neck. The shape of each cross section is not an ideal circle, and each cross section is not the same along the aortic neck length. Therefore, we can measure, on the same cross section, different aortic neck diameters (diameters at different positions), as well as the diameter at the same position of different cross sections of the neck. As a result, we can measure the minimum, the maximum, and the mean value of all diameters of the neck. The diameter that is used to decide if the neck is suitable for endovascular repair, is the maximum diameter of the orthogonal cross section just below the lower renal artery (5, 6). Although today there are no practical clinical applications for the measurement of all diameters, the distribution of the diameters of the neck along its length allows the creation of a numerical estimation of the neck’s shape. The mean value of the difference of the diameters of the subsequent cross sections can define the shape of the neck. For an aortic neck which is an ideal cylinder, the mean of the differences between the diameters would be nil.

**Neck shape**: The aortic neck is ideally a cylinder. However, this is a simplification of the true morphology of the neck. In fact, any aortic neck which does not have a morphology close to a true cylinder is not a suitable proximal fixation zone for endovascular repair (Fig. 5). Therefore, aortic necks suitable for proximal fixation zones for endovascular repair can be assumed to have a straight (or near straight) MCLP and the diameter change, along its length, should be small (less than 5 mm) (7) (Fig. 4).

The shape or configuration of the neck is usually determined by visual examination of coronal views of the aorta at different angle projections. Necks that have a reverse funnel shape are poor candidates (Fig. 5). The distribution of the diameters of the neck at 1 mm intervals gives numerical data for the shape determination of the aortic neck. The mean of the differences of all the diameters can be a parameter that defines the irregularity of the neck shape. Numerical limits for this number can then -through future clinical research- be created after comparing different numerical values of various necks to the clinical outcome after endovascular repair.

**Neck atheroma and thrombus**: Aortic neck atheroma and thrombus formation are factors which are visually detected and judgement on suitability is dependent on experience and practice. A heavily calcified aorta must be approached with caution as it may preclude graft deployment. A considerable amount of thrombus in the neck poses a question about permanent fixation and
Neck angulation: We have considered that the aortic neck suitable for endovascular repair has a morphology close to a cylinder. This allows us to define the axis of the aortic neck as the straight line between the MCLP of the aorta at the level of the orifice of the lower renal artery and the MCLP of the aorta at the start of the aneurysm. The aortic neck is the anatomic segment of the aorta which lies between two segments. The first segment is the aorta above the renal arteries, the second is the cylindrical neck, and the third segment is the aneurysm. Between these three segments two angles are defined. The proximal aortic neck angle is the angle between the axis of the neck and the axis of the suprarenal aorta. The distal aortic neck angle is the angle between the axis of the neck and the axis of the lumen of the aneurysm (Fig. 6). The axis of the suprarenal aorta is defined as the straight line between the MCLP of the aorta at the level of the orifice of the superior mesenteric artery and the MCLP of the aorta at the orifice of the lower renal artery. The axis of the lumen of the aneurysm is the straight line between the MCLP at the start of the aneurysm and the MCLP at the end of the aneurysm. When the lumen of the aneurysm is not straight, the first 2.0 cm at its proximal end is used to determine the axis of the aneurysm (Fig. 7).

It is well known that in the majority of the published reports, aortic neck angulation is defined as the distal aortic neck angle. The definition of neck angulation by describing and measuring two angles, the proximal and the distal, is for us more realistic than defining neck
Fig. 7
An example of a nil proximal aortic neck angle. Because the MCLP of the aneurysm is not straight, the axis of the aneurysm is defined by the MCLP at its start and the MCLP at 2 cm distally.

Fig. 8
The proximal and distal neck angles in post-implantation three dimensional CT images.

The literature contains a number of recommendations regarding aortic neck angulation. The Eurostar trial (8), after an analysis of 2146 patients, showed that neck angulation was related to migration or type I endoleaks. Similar results were reported by Albertini et al. (9) and Strenberg et al. (10). However, these studies refer primarily to the distal aortic neck angle. Petrik et al. (11) reported no difference in neck angulation (distal aortic neck angle), between patients with and without type I endoleaks. In this study, no patient with a distal aortic neck greater than 60 degrees was offered an endovascular repair as was the case in this series we report.

Anatomic parameters of the iliac arteries

The value of the definition of the anatomy of iliac arteries in endovascular AAA repair is related to: 1) the presence of a segment to serve as the distal fixation zone and 2) the diameter and tortuosity of these vessels, to allow access with wires, sheaths and stent grafts.

Iliac artery diameter: The minimal diameter of the iliac arteries (common and external iliac) is measured to make sure that access can be obtained with the sheath and/or device. The measurements are based on the cross sectional areas of the flow lumen of the arteries and therefore the diameter measured is the diameter of the lumen of the artery. The presence or absence of iliac artery occlusive disease, should be noted (12).

Iliac artery calcification and thrombus: These parameters cannot be estimated by a validated quantitative method. Experience influences visual judgement.

Iliac artery tortuosity: Angulation and tortuosity of the iliac arteries makes deployment of the endograft
more difficult. Increased angulation and tortuosity can cause embolization and dissection. With methods currently available, it is difficult to describe tortuosity of the iliac arteries since they can be variably tortuous throughout their length. Angulation may change along the length of the iliac arteries and may be particularly different in the common and the external iliac arteries. We believe as others (11) that the proximal iliac angle is an important parameter of aortoiliac tortuosity that may play a role in postoperative clinical outcome. The proximal iliac angles are defined as the angles between the axis of each iliac artery (c : right, d : left) and the axis of the lumen of the aneurysm. The axis of each iliac artery is defined as the straight line between the MLCP at the level of aortic bifurcation and the MLCP of each iliac artery at 2.0 cm distally. The axis of the aneurysm is described earlier, but when its lumen is not straight, the last 2 cm at its distal end is used to determine its axis.

Conclusion

Endovascular surgery has undoubtedly had a dramatic effect in the treatment of abdominal aortic aneurysm repair. Although short and medium term results are encouraging, there are still reports of isolated adverse events of rupture, migrations and late onset endoleaks, especially in patients with increased angulation of the proximal aortic neck. Although, the value of the preoperative anatomic evaluation has been strongly emphasized, the definition and quantification of the anatomic parameters still needs further definition. Three dimensional reconstructed CTA images provide a suitable imaging method for clinical research in this area. We have defined aortic neck angulation as two separate angles. Our data suggest that the proximal aortic neck angle is a parameter of aortic neck angulation that has to be measured. A prospective study is required to answer the question of what is the limit of the size of the proximal aortic neck angle that prevents the need for secondary procedures after endovascular AAA repair. Future research should focus on the precise and standard definition of aortic neck shape, aortic calcification and thrombus and a quantitative determination of the overall aortoiliac tortuosity.

References


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