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Aortic Curvature Instead of Angulation Allows Improved Estimation of the True Aorto-iliac Trajectory

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WHAT THIS PAPER ADDS

Aortic neck angulation influences the accuracy of endograft placement and long-term endovascular abdominal aortic repair outcome. To date, a uniform angulation measurement method is lacking and the current methods are prone to subjective interpretation and assume a triangular oversimplification of the aortic neck. The present paper introduces and validates a new method that allows uniform assessment of aortic neck curvature along the center lumen line.

Objective: Supra- and infrarenal aortic neck angulation have been associated with complications after endovascular aortic aneurysm repair. However, a uniform angulation measurement method is lacking and the concept of angulation suggests a triangular oversimplification of the aortic anatomy. (Semi-)automated calculation of curvature along the center luminal line describes the actual trajectory of the aorta. This study proposes a methodology for calculating aortic (neck) curvature and suggests an additional method based on available tools in current workstations: curvature by digital calipers (CDC).

Methods: Proprietary custom software was developed for automatic calculation of the severity and location of the largest supra- and infrarenal curvature over the center luminal line. Twenty-four patients with severe supra- or infrarenal angulations ($\geq 45^{\circ}$) and 11 patients with small to moderate angulations ($<45^{\circ}$) were included. Both CDC and angulation were measured by two independent observers on the pre- and postoperative computed tomographic angiography scans. The relationships between actual curvature and CDC and angulation were visualized and tested with Pearson's correlation coefficient. The CDC was also fully automatically calculated with proprietary custom software. The difference between manual and automatic determination of CDC was tested with a paired Student *t* test. A *p*-value was considered significant when two-tailed $\alpha < .05$.

Results: The correlation between actual curvature and manual CDC is strong (.586–.962) and even stronger for automatic CDC (.865–.961). The correlation between actual curvature and angulation is much lower (.410–.737). Flow direction angulation values overestimate CDC measurements by 60%, with larger variance. No significant difference was found in automatically calculated CDC values and manually measured CDC values.

Conclusion: Curvature calculation of the aortic neck improves determination of the true aortic trajectory. Automatic calculation of the actual curvature is preferable, but measurement or calculation of the curvature by digital calipers is a valid alternative if actual curvature is not at hand.

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INTRODUCTION

During the last decade endovascular aneurysm repair (EVAR) has become the preferred treatment modality for infrarenal aortic aneurysms (AAA), with superior short-term results compared with open surgery.[1] However, long-term outcome is highly dependent on patient selection and procedure planning.[2,3] In challenging aortic neck anatomy, EVAR has been associated with substantial complications, including endograft migration and type Ia endoleaks.

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Among hostile neck anatomy characteristics, both suprarenal angulation (>45°) and infrarenal angulation (>60°) are important.[4–9]

Despite inclusion of large numbers of patients in previous EVAR studies, it is difficult to determine the influence of each individual aortic neck characteristic on post-EVAR complications. One of the difficulties is the lack of a standardized measuring methodology. Angulation is measured in different ways, compromising reliable comparisons between studies as well as the interpretation of endograft manufacturers' instructions for use (IFU).

Over the past 10 years, more and more preoperative sizing and planning has been based on the center luminal line (CLL) reconstructions with the use of a 3D workstation. To determine supra- and infrarenal angulation, 3D workstations offer the option of measuring the angle between the flow direction from the suprarenal aorta to the aortic neck and from the aortic neck to the aneurysm sac along the CLL, respectively. This method is based on the 2D method described by van Keulen and coworkers, and adapted for measuring in three dimensions along the CLL.[10] The angulation measurement over the CLL is referred to as the flow direction angulation method (FDAM).

By using the FDAM, the maximum angle at the crossing of two flow lines is measured. For gentle curvature, the intersection is located far from the center luminal line, and therefore it overestimates the true aortic curvature. Also, measuring the change in flow direction may underestimate the risk factors for EVAR, as tortuous segments will be ignored.

In the present study, a new method is proposed that describes the actual curve of the aorta that is followed by the endograft during deployment throughout the entire aortic neck and into the aneurysm. A better term to describe this aortic trajectory would be curvature instead of angulation, as angulation suggests a triangular oversimplification of the aortic anatomy. Curvature takes into account not only the severity of the angulation, but also the shape of the trajectory over which the angulation is present. Angulation, contrary to curvature, cannot differentiate between sharp and long curves, while large aortic neck curvature could result in suboptimal endograft deployment (Fig. 1).

In this paper, the method for calculating aortic curvature is described and tested on a cohort of 35 EVAR patients. The curvature is defined by a mathematical formula and will be referred to as "actual curvature." As this formula for actual curvature is not available in all clinically used workstations, a semi-automated measurement method is described that enables aortic curvature measurements with digital calipers, called "curvature by digital calipers" (CDC). The hypothesis is that CDC is a good approximation of the actual (mathematically calculated) curvature. Both angulation by the flow direction method (FDAM) and CDC will be compared with the actual curvature to test this hypothesis.

METHODS

Curvature and angulation

The 3mensio workstation (3mensio Vascular 7.0, Medical Imaging BV, Bilthoven, The Netherlands) was used to obtain the CLL at 1 mm increments from the CT scan. This CLL was used to obtain the supra- and infrarenal curvature and angulation. Matlab 2013b (The MathWorks, Natick,

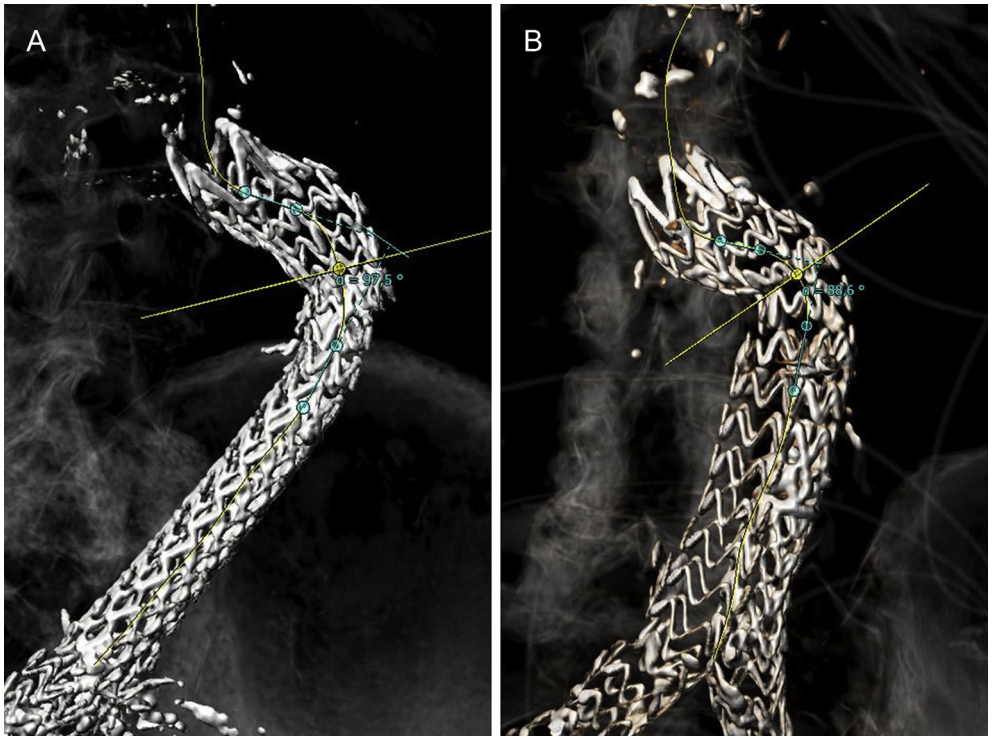

Figure 1. Endograft segmentation in two heavily angulated aortas, the angulation is measured with the flow direction angulation method (FDAM). (A) Large angulation (97.5°), but low curvature, endograft is correctly deployed. (B) Large angulation (88.6°) and large curvature, the endograft is slightly kinked. A lower risk for migration and type Ia endoleaks is suspected in (A) compared with (B).