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Circumference as an alternative for diameter measurement in endovascular aneurysm repair

Ignace F.J. Tielliu [a,*], Ruben V.C. Buijs [a], Marcel J.W. Greuter [b], Tryfon Vainas [a], Bas M. Wallis de Vries [a], Ted R. Prins [b], Clark J. Zeebregts [a]

[a] Department of Surgery, Division of Vascular Surgery, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands
[b] Department of Radiology, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands

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ABSTRACT

Appropriate sizing of endografts for endovascular aneurysm repair has traditionally been performed by one standardized method. By measuring the average of the minor and major axes in the sealing zone, the endograft size is traditionally calculated. However, no adequate scientific evaluation has been performed to validate this method. The guidelines that were published are based on theories and experience, more than scientific evidence. In case the central lumen line artery cross-section is a circular disk, the vessel diameter is a reliable estimation. Yet the aortic neck cross-section may not always be geometrically a perfect circular disk. Application of the standardized method might therefore lead to inaccurate endograft sizing, potentially leading to endoleaks. We hypothesize that in these cases the circumference of the vessel is a mathematically correct reference to deduct the appropriate endograft diameter. The following formula was applied in this study: diameter of the corresponding circle (d) equals circumference (C) divided by π ($d = \frac{C}{\pi}$). This study provides a theoretical analysis of the mathematical implications of this method. Only in case of highly irregularly shaped cylinders, the circumference-based method was more accurate than the standardized method. Nonetheless, the circumferential method was a practical reference in case the aortic neck was irregularly shaped. Also, the circumference method was accurate in all cases in deducting the diameter of a matching circle. Therefore, the hypothesis that was raised in this study has a strong theoretical base. We predict that in case this hypothesis holds true in the clinical practice, application of the circumference method might lead to less endoleaks than the standardized method.

Introduction

Endovascular aneurysm repair (EVAR) implicates measurement of sealing zones proximal and distal to the aneurysm for optimal stent graft selection to ensure adequate sealing and fixation. Inappropriate sizing could in theory result in a higher incidence of endoleaks due to undersizing or oversizing with infolding of the endograft [1,2]. Traditionally, sizing of the artery to select the optimal endograft diameter was done by measuring the diameter of the artery in the axial slices of a computed tomography (CT) angiogram. However, when the artery is angulated with respect to the imaged slice, the axial CT shows an ellipsoid shaped section of the aorta. In that case the smallest wall-to-wall diameter in any direction of the artery is generally selected [3]. This technique, however, is correct only in cases where the artery is a perfect cylinder and the cross-section perpendicular to the central lumen line (CLL) of the artery is a perfect circular disk. Moreover, it is nowadays common-practice to measure blood vessel diameters on the CLL reconstruction images instead of on axial slices.

When for reasons of angulation, atherosclerotic degeneration, or dissection, the artery is not a cylinder but instead more flattened in one direction, the axial central lumen line cross section will have the shape of an ellipse with a certain degree of eccentricity. In this event, it has been advised to estimate the vessel diameter by averaging the major and minor luminal axes [4]. It remains to be seen however, whether this is the best approach for determining vessel diameter and subsequently endovascular stent-graft size or whether an alternative approach may yield better results.

Hypothesis

In order to achieve sealing, the outer surface of the endograft should be in apposition to the arterial luminal surface. The arterial

* Corresponding author at: Department of Surgery, Division of Vascular Surgery, University Medical Center Groningen, University of Groningen, Hanzeplein 1, P.O. Box 30001, 9700 RB Groningen, The Netherlands. Tel.: +31 50 3613382; fax: +31 50 3611745.
E-mail address: i.f.j.tielliu@umcg.nl (I.F.J. Tielliu).

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circumference may therefore be the best determinant of graft size. For cylindrical arteries, the graft size may be calculated from the aortic neck diameter. This may be troublesome in necks with a non-cylindrical shape, potentially leading to endograft failure like endoleak type 1A.

We hypothesize that the vessel circumference is a mathematically correct reference for the vessel diameter calculation and endograft diameter selection. This technique could be useful when the artery cross-section perpendicular to the CLL is not a disk. The circumference can be used to deduct the matching circle diameter. Subsequently, the matching circle diameter is the reference to select the stent-graft diameter.

Technique

The area perpendicular to the CLL of a cylindrical artery is a circular disk. In that case the disk diameter is a good reference for endograft sizing. When the artery has a cylindrical shape, the circumference could also be used as a reference to deduct the matching diameter of the disk the section of the artery at that point is.

The circumference (C) of a circle with radius r is:

$$C = 2\pi r \tag{1}$$

In cases where the section perpendicular to the CLL of the artery is not a circular disk, there is not a single diameter of the artery at that point that is a good reference for sizing. The circumference of the artery section in this case is the best reference to deduct the corresponding circle diameter.

Counter intuitively, the section area as opposed to the disk circumference cannot be used as a reference to deduct the circle diameter. Fig. 1 shows two geometric forms with equal circumferences and different areas. For apposition of the stent-graft to the arterial wall, it will have to follow the circumference rather than fill up the area. In both cases, the same stent-graft diameter would have to be chosen to gain apposition, as the circumference is the same whereas the area is smaller in the form following the concave dashed line as compared to the convex full line.

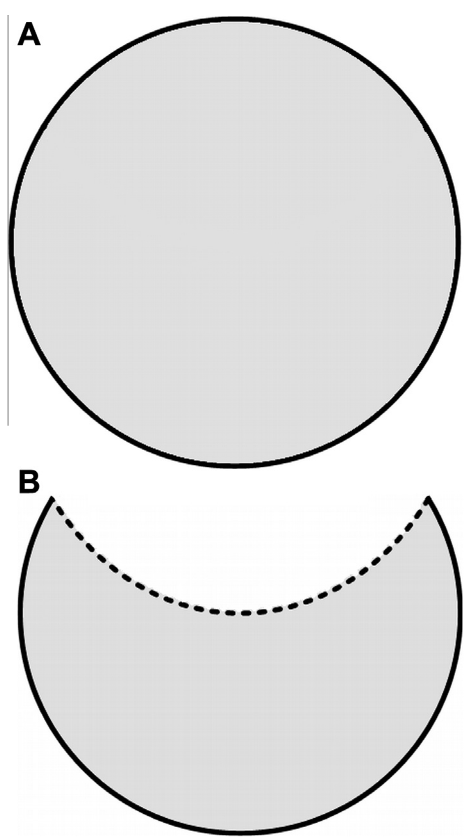

Fig. 1. Illustration of two geometric forms simulating blood vessels and with different areas (shaded) but with a similar circumference. (A) has the same circumference as (B), but (A) has a much larger area than (B).

With a perfect ellipsoid vessel shape, the ellipse can be described by major ($2a$) and minor axis ($2b$) lengths (Fig. 2). In the conventional method, the corresponding circle diameter (d) is approximated by the average of both axes lengths:

$$d = \frac{2a + 2b}{2} \tag{2}$$

To approximate the vessel diameter by using the circumference of the ellipse, one could use Ramanujan's approximation [5], and the corresponding diameter of the vessel is:

$$d = 3(a + b) - \sqrt{(a + 3b)(3a + b)} \tag{3}$$

In Fig. 2 the difference between the corresponding vessel diameters computed with the conventional method (average of axes) and with the proposed method (circumference) as a function of the ratio between major and minor axes of the ellipse is plotted. Although the proposed method gives a better approximation of the vessel circumference, the underestimation of the diameter by the conventional method only becomes >5% when the ratio between the axes becomes <0.37. (Table 1) This is true for an ellipsoid vessel with a severe eccentricity.

Let us now assume an irregularly shaped artery (Fig. 3) without an axis that is a good reference for the matching circle diameter. The circumference of the irregularly shaped form equals the matching circle with the same circumference.

Practically, the artery circumference can be measured directly on the CLL axial reconstruction image. With the circumference data, the corresponding circle diameter can be calculated as is illustrated in Fig. 4:

$$d = \frac{C}{\pi} \tag{4}$$

Evaluation of the hypothesis

This report illustrates the validity of the hypothesis of the artery circumference as a reference for sizing and planning in EVAR. In the literature dating back from 1991 when the first EVAR cases

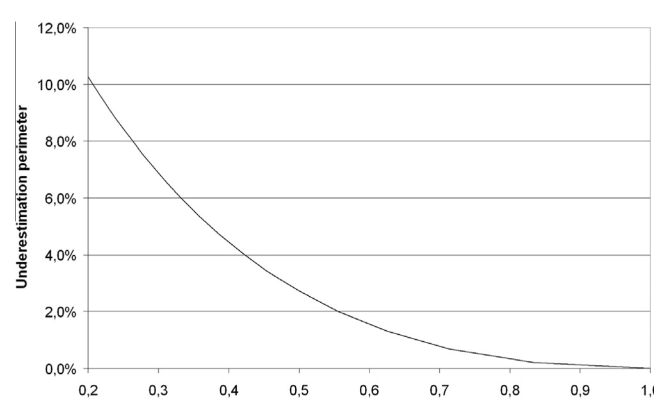

Fig. 2. Determination of the diameter of a circle with a circumference that corresponds with an ellipse with the same circumference. Underestimation of the circumference of the ellipse, approximated by the average of the major axis ($2a$) and the minor axis ($2b$) (conventional method, P2), compared to Ramanujan's approximation [5] (proposed method, P1), as a function of the ratio b/a.