Centerline is Not as Accurate as Outer Curvature Length to Estimate Thoracic Endograft Length

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WHAT THIS PAPER ADDS
This study describes a new sizing method for thoracic endovascular aortic repair and the limitation of the current sizing method.

Background: To assess the accuracy of the aortic outer curvature length for thoracic endograft planning.
Methods: Seventy-four patients (58 men, 66.4 ± 14 years) who underwent thoracic endovascular aortic repair between 2009 and 2011 treated with a Cook Medical endograft were enrolled in this retrospective study. Immediate postoperative CT scans were analysed using EndoSize software. Three vessel lengths were computed between two fixed landmarks placed at each end of the endograft: the straightline (axial) length, the centerline length and the outer curvature length. A tortuosity index was defined as the ratio of the centerline length/straightline length. A Student *t* test and a Pearson correlation coefficient were used to examine the results.
Results: We found a significant difference between the centerline length (135.4 ± 24 mm) and that of the endograft (160 ± 29 mm) ($p < .0001$). This difference correlates with the tortuosity index ($r = .818$, $p < .0001$), the endograft length ($r = .587$, $p < .0001$), and the diameter of the endograft ($r = .53$, $p < .0001$). However, the outer curvature length (161.3 ± 29 mm) and the endograft length (160 ± 29 mm) were similar ($p = .792$).
Conclusion: The outer curvature length more accurately reflects that of the deployed endograft and may prove more accurate than centerlines in planning thoracic endografts.

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INTRODUCTION

Currently, sizing prior[1] to endovascular aortic repair is performed using workstations with dedicated three-dimensional (3D) reconstruction software. To calculate aortic lengths and diameters and overcome the hazard of shortening inherent to axial imaging, a centerline extraction is useful in order to estimate true vessel length. This method is widely used and is generally adopted as the "gold standard". Nevertheless, we have found that thoracic endovascular aortic repair (TEVAR) distal landing zones do not always lie where the centerline-based plan might predict. The usual error is that the length of the endograft is shorter than the length planned. This phenomenon has been previously described in abdominal EVAR.[1] Potential explanations include shortening of the endograft during deployment and the geometric consequences of the curvature of the thoracic aorta. Previous investigators have shown that there is a difference between aortic length estimated using a centerline reconstruction from that obtained by measuring along the aortic wall.[2] The aim of this study was to assess the accuracy of the aortic outer curve length as a predictor of endograft length.

METHODS

Between 2009 and 2011, data from 74 consecutive patients (58 men, 16 women) who underwent TEVAR were collected in a prospective database and were included in this retrospective analysis. The mean age of the patients was 66.4 ± 14 years (range, 19–89 years). The study group comprised two types of aortic pathology: 45 patients (60.8%, Group 1) with acute type B aortic dissections and 29 (39.2%, Group 2) with degenerative aneurysms. All patients were treated using a Cook Medical device (William Cook Europe, Biaeverskow, Denmark). Planning of all thoracic endografts implanted in the current study estimated endograft length on centerline curved planar reconstructions. The immediate postoperative computed tomography angiography (CTA) was used for measurements in order that the results were not skewed by later aneurysm shrinkage. All CTAs were analysed with EndoSize software[3]

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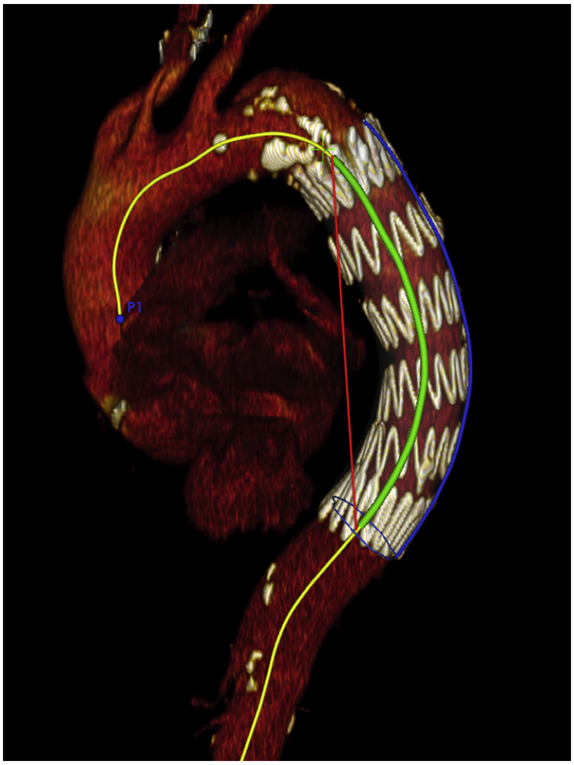

Figure 1. The EndoSize software calculates three lengths: the straight line (red), the centerline (green) and the outer line (blue). P1 is the start of the centerline.

(Therenva, France) using automatically extracted centerlines. For each case, a proximal and distal landmark was placed on the centerline corresponding to the ends of the endograft. Three measurements were made between these landmarks (Fig. 1): the centerline length, the straightline (axial) length and the outer curvature length. The straightline length is the distance between the two landmarks using the straightline in 3D. This distance is automatically computed by the software. The outer curvature length is calculated using a virtual endograft (circular tube) (Fig. 2), which is constrained on the centerline. The outer curvature length is then automatically computed by the maximal path along the tube. For each patient the diameter of this virtual endograft was calculated using the diameter of the implanted endograft. This outer curvature length is not the real length of the outer aortic wall and is consequently independent of the size of the aneurysmal sac or the presence of thrombus. We used a calculated index of tortuosity based on the reporting standard for thoracic endovascular aortic repair.[4,5] This was defined as the ratio between the centerline and the straightline lengths. In cases where several endografts were deployed in the thoracic aorta, only the proximal component was considered. (The end of each component is readily identified by the gold markers located on both ends of the endograft.)

Statistical analysis

Data are presented as mean ± standard deviation. Quantitative variables were compared using a Student *t* test. Correlation was calculated using Pearson's coefficient (*r*). The statistical level of significance was 5%.

RESULTS

Centerline length

There was a statistically significant difference in the lengths measured using centerlines (135.4 ± 24 mm) compared with that of the endografts (160 ± 29 mm) ($p < .0001$). The mean difference between the centerline length and the endograft length was 24.6 ± 11 mm (range, 1–50 mm). As a proportion of graft length, the relative difference was

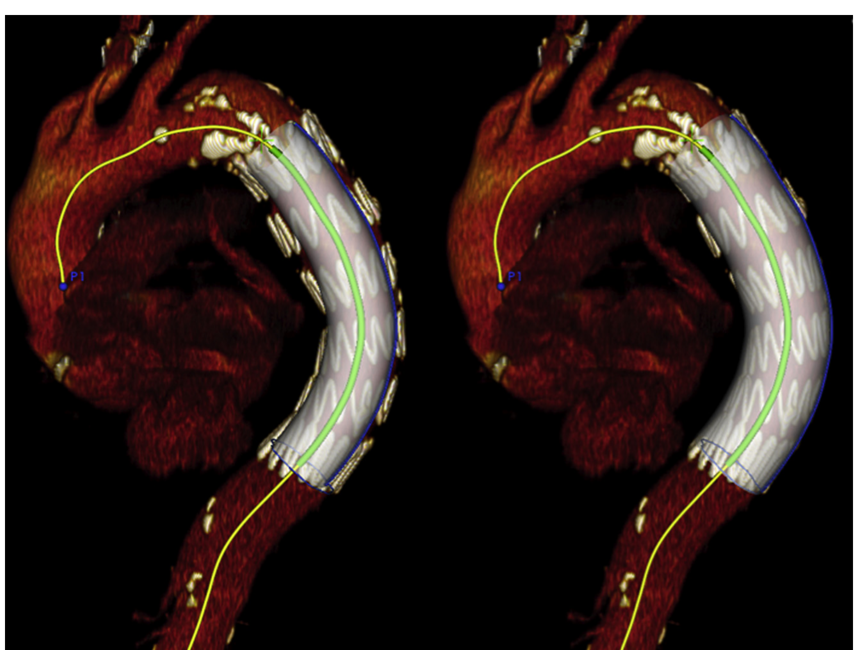

Figure 2. The outer wall length is calculated from a virtual endograft model (tube along the centerline) with a designated radius.

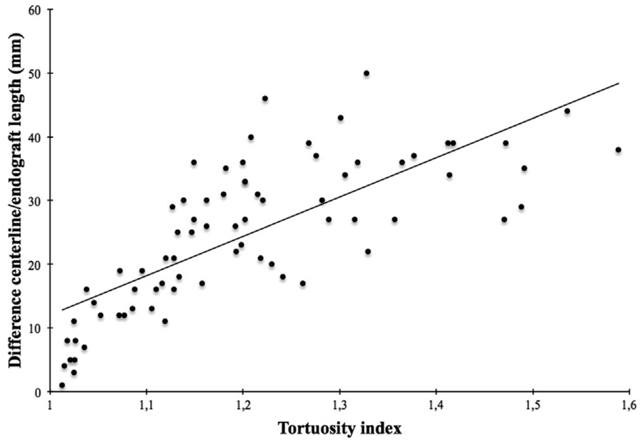

Figure 3. Correlation between the tortuosity index and the absolute difference between the centerline distance and the endograft length.

15.1 ± 6.2% (range, 1—23%), with centerline length consistently returning “shorter than real” lengths.

Not surprisingly, both of these differences showed significant correlation with the tortuosity index (absolute length: $r = .818$, $p < .0001$) and endograft length ($p = .587$, $p < .0001$) (Figs. 3 and 4), as did the relative difference (tortuosity index: $r = .723$, $p < .0001$); endograft length ($r = .284$, $p = .014$). There is also a significant relationship between absolute difference between the centerline and the endograft length and the diameter of the endograft ($r = .53$, $p < .0001$) (Fig. 5).

Outer curvature length

No significant differences were observed when comparing the lengths of the outer curvature (161.3 ± 29 mm) and that of the endografts (160 ± 29 mm) ($p = .792$). The mean absolute difference between the outer curvature length and the endograft length was 1.3 ± 2 mm (range, −3 to +7 mm), and the relative difference was 1.1 ± 1.1% (range, −2.4 to +5.8%). Fig. 6 illustrates the potential for over- or underestimated endograft lengths as a function of the measured outer curvature length. The outer curvature length was shorter than the endograft length in 11 cases (14.9%), with a maximum relative underestimation of 2.4%. The outer curvature length was within 1 mm of the endograft length in 18 cases (24%). In 45 cases (60.8%), the outer curvature length was longer than the endograft length with a maximum relative length overestimation of 5.8%.

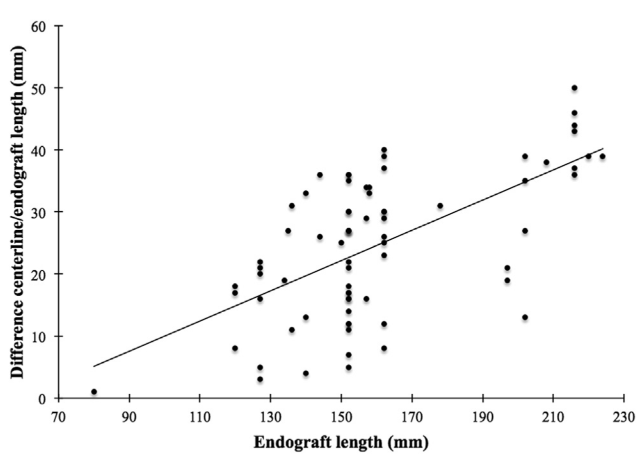

Figure 4. Correlation between the endograft length and the absolute difference between the centerline distance and the endograft length.

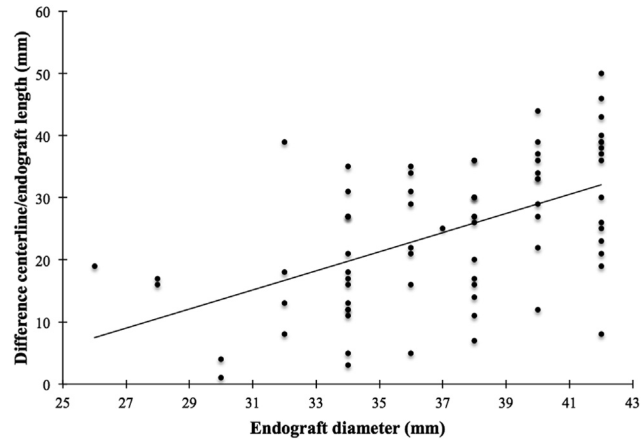

Figure 5. Correlation between the endograft diameter and the absolute difference between the centerline distance and the endograft length.

Subgroups analysis

Data comparing the dissection and degenerative aneurysm groups are presented in Table 1. The variance between the centerline length and the endograft length was greater in the dissection group (28.3 ± 10.3 mm) than in the aneurysm group (22.2 ± 11.8, $p = .027$). However, the aortic pathology was not associated with a difference in the outer curvature length and endograft length (1 ± 2.3 mm in aneurysm group and 1.6 ± 1.4 mm in dissection group, $p = .237$). In the aneurysm group no correlation was observed between the aneurysm sac diameter (65.3 ± 7.9 mm) and the length of the endograft ($p = .802$).

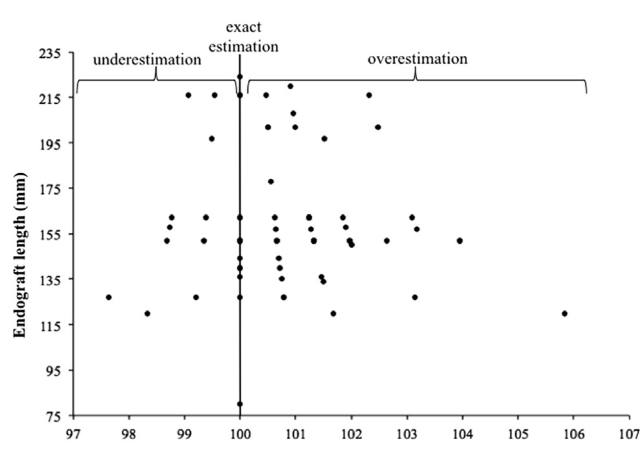

Figure 6. Accuracy of the estimated outer wall length compared to the real endograft length.

Table 1. Values of the lengths computed with EndoSize software and characteristics of the endograft in the total population and in the two groups.

	Population ($n = 74$)	Dissection ($n = 45$)	Aneurysm ($n = 29$)	p-Value
Centerline distance (mm)	135.4 ± 24	137.3 ± 23.9	134.2 ± 24.1	0.581
Outer distance (mm)	161.3 ± 29.4	167.2 ± 29.5	157.5 ± 28.9	0.163
Endograft length (mm)	160 ± 29.2	165.6 ± 29.6	156.4 ± 28.8	0.188
Endograft diameter (mm)	37.2 ± 3.9	37.4 ± 3.7	37 ± 4.1	0.689
Tortuosity index	1.2 ± 0.14	1.25 ± 0.16	1.18 ± 0.12	0.04

Distance, length and diameter are given in millimetres.

DISCUSSION

Few studies have analysed the discrepancy between the planned and the actual landing zone of aortic endografts. This mismatch is difficult to predict using standard radiological measurement techniques, but has been studied by White et al.[1] Our results cannot be compared with theirs, principally because their analysis describes first-generation endografts deployed in the abdominal aorta. Nevertheless, they identified that the landing zone was more proximal than expected in half of their cases. There are two obvious possible explanations: the endograft itself may shorten during deployment, or sizing may be inaccurate. The “industry standard” for the estimation of aortic length uses corrected centerline extraction. This method has limitations and the apparent aortic length varies depending on how it is measured — centerline of flow, inner or outer wall measurements can all be considered. The difference between the measured aortic lengths is most dramatic in curved, large-diameter vessels such as the thoracic aorta. Wors et al.[2] have derived a robust and reliable mathematical model that describes all of the anatomical parameters of the thoracic arch. Although intuitive, the variability in measured aortic arch length calculated in this study concurs with our own results. There are potentially important differences between the apparent length estimated using centerlines and those measured from the greater curve outer wall. In our study this difference has been measured to be as much as 50 mm. Our results confirm increasing discrepancies with greater aortic curvature, length and diameter. Whittaker et al.[6] reported a similar phenomenon in the case of the abdominal aorta with their experience of the Excluder endograft (WL Gore and associates, Flagstaff, AZ, USA). Indeed, in the setting of abdominal aortic aneurysms, endograft shortening bore a relationship to iliac artery tortuosity. The thoracic aorta is a larger, more tortuous vessel than most abdominal aortas. Therefore, the potential for thoracic endograft length underestimation is likely to be greater than it is in the treatment of the abdominal aorta. However, sizing is critical and it is known that thoracic tortuosity is one of the major anatomical predictors of endoleak.[7–9] The choice of device length depends on the extent of the aneurysm or dissection and on the manufacturers’ instructions for use. Our results clearly demonstrate that the length of the deployed endograft is most closely predicted by estimation of the outer wall length. The endograft conforms to the aortic anatomy. Therefore, the centerline measurements are not ideal for sizing endograft length. It is true that this lack of accuracy has little effect on the technical success because the endotherapist can implant an additional distal extension endograft to make good any unexpected shortening. The proposed lengths of thoracic endografts are limited, thus the endograft selected is often longer than required. In cases with large thoracic aneurysms extending from the arch to the distal thoracic aorta, it is usually recommended to implant more than one thoracic endograft. Tromboning these endografts is an easy method, compensating for the difficulties in predicting the accurate length. Implantation of the first endograft will require focusing only on the proximal sealing zone, and implantation of the second endograft will necessitate focusing on the distal sealing zone and the overlap zone. To avoid type 3 endoleaks and late disconnection, a long overlap between the endografts is mandatory. In the era of complex aortic endovascular treatment, accuracy of measurement is critical to the successful use of custom-made devices, such as fenestrated and branched endografts,[10] particularly so when treating pathologies of the aortic arch[11,12] where vessel curvature is at its maximum.

The majority of sizing of complex endografts is performed in the manufacturers’ planning centres. In the near future, with the release of “off-the-shelf” fenestrated and branched endografts,[13] surgeons will have to perform their own complex sizing, particularly in the management of emergencies. Therefore, these measurement subtleties must be recognized and sizing tools that take them into account are required. The EndoSize software does not require advanced experience with 3D workstation planning, but adjustment of

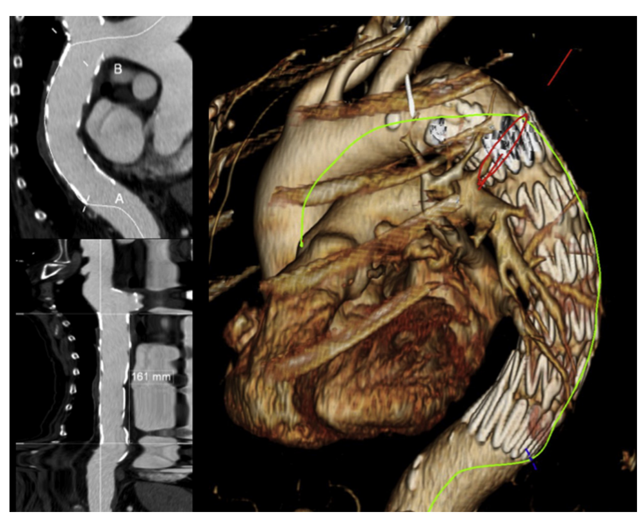

Figure 7. With another sizing software (Tera Recon Inc., San Mateo, CA, USA) the centerline can be moved to the outer curvature to calculate the endograft length (the real endograft length in this example is 157 mm, the length calculated by this modified centerline is AB=161mm).

the centerline remains critical to obtain accurate automated outlining of the outer curve measurements.

One of the limitations of this study is access to the outer curvature length. Currently, only EndoSize software provides such a measurement. With most planning software it is possible to approximate the length of the outer wall simply by manually moving the points of the automated centerline of flow to the external wall of the aorta (Fig. 7). In addition, in the current study, the proximal landing zone of the thoracic endograft was always distal to the origin of the left common carotid origin. Our analysis is thus restricted to the descending thoracic aorta and not applicable to lesions located in the arch.

CONCLUSION

Although centerlines of flow are useful in the sizing of endografts, in the planning of TEVAR, they usually underestimate the length of endograft required. The greater the curvature and larger the vessel, the more profound the underestimate. The outer curvature length is a more reliable and accurate estimate of the true length needed to effectively exclude aortic aneurysms and dissections.

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CONFLICT OF INTEREST

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