Interobserver and intraobserver variability in measuring the tortuosity of the thoracic aorta on computed tomography

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ABSTRACT

Objective: The variability in measuring the tortuosity of the thoracic aorta has not been previously studied. This study evaluated the interobserver and intraobserver variability of major methods used for measuring the tortuosity of the thoracic aorta in patients with aortic arch or descending thoracic aortic aneurysm.

Methods: This retrospective study enrolled 66 patients with aortic arch or descending thoracic aortic aneurysm who had undergone thoracic endovascular aortic repair. Two radiologists used preoperative computed tomography images to measure the tortuosity of the thoracic aorta at multiple segments by using the fitting circle diameter, tortuosity index, and centerline angle methods; these measurements were repeated after an interval of >28 days. The variability of the methods was analyzed for interobserver and intraobserver reliability and agreement. The estimated intraclass correlation coefficient (ICC) was used to analyze the reliability. The Bland-Altman plot was used to analyze the interobserver and intraobserver agreement. The association between aortic characteristics, including calcification, luminal irregularity, shape, and diameter, and the variability of the measurements was also analyzed.

Results: The interobserver ICC estimates for the tortuosity index at multiple aortic segments, centerline angle methods at the supra-aortic branch orifices, and fitting circle diameter on the greater and lesser curvature sides were 0.97 to 0.98, 0.39 to 0.75, and 0.82 to 0.84, respectively. The corresponding intraobserver ICC estimates were 0.98 to 1.00, 0.44 to 0.75, and 0.82 to 0.85, respectively. In the agreement analysis, the 95% limits of agreement for the tortuosity index, centerline angle, and fitting circle diameter were −5.5% to 5.6%, −10.9% to 10.9%, and −18.0% to 24.0%, respectively. The tortuosity index had the highest ICC estimate and narrowest 99.5% limits of agreement of the three methods. Aortic characteristics, including calcification, grade of atheroma, aneurysm shape, and diameter, were not associated with the variability of the tortuosity index method in the thoracic aorta.

Conclusions: The tortuosity index method has low interobserver and intraobserver variability in measuring the tortuosity of the thoracic aorta in patients with thoracic aortic aneurysm. The characteristics of the aorta and aneurysm are not associated with the interobserver or intraobserver variability of the tortuosity index. (J Vasc Surg 2018;■:1-10.)

Keywords: Thoracic aorta; Computed tomography; Tortuosity; Interobserver variability; Intraobserver variability

Thoracic endovascular aortic repair (TEVAR) for thoracic aortic disease has the advantage of being less invasive than open repair; however, it has complications associated with the stent graft, such as endoleak and graft failure. Along with the diameter of a diseased aorta,[1] the tortuosity of the thoracic aorta is a morphologic factor that could be associated with the postoperative complications of TEVAR. The more tortuous the thoracic aorta is, the more likely is the occurrence of incomplete endograft apposition with the thoracic aortic wall, and this increases the incidence of endoleak after TEVAR.[2,3] Because the morphology of the thoracic aorta is complex, there is no consensus on which parameter should be used to characterize the tortuosity of the aortic arch. Hence, several parameters have been proposed to represent the tortuosity of the thoracic aorta, including fitting circle diameter,[4,5] aortic arch height,[6] centerline angle,[7] and tortuosity index.[8,9]

To the best of our knowledge, whereas previous studies have reported the interobserver and intraobserver variability of measuring the degree of angulation in patients

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with infrarenal abdominal aortic aneurysm by measuring the angle along the aortic centerline,[10] no study has focused on the variability of the parameters of measuring the tortuosity of the thoracic aorta. To be a reliable imaging marker in clinical practice, a parameter needs to be reproducible by having low interobserver and intraobserver variability.

In this study, we evaluated the interobserver and intraobserver variability of parameters for measuring the tortuosity of the thoracic aorta, including the tortuosity index method mentioned in the reporting standards for TEVAR by the Society for Vascular Surgery.[11]

ARTICLE HIGHLIGHTS

- **Type of Research:** Single-center retrospective cohort study
- **Take Home Message:** Analysis of arch and descending thoracic aortic tortuosity in 66 patients undergoing thoracic endovascular aortic repair demonstrated that the tortuosity index had the lowest intraobserver and interobserver variability compared with the centerline angle and fitting circle diameter methods of measurement.
- **Recommendation:** This study suggests that the tortuosity index is the most reliable method for determining tortuosity of the aortic arch and thoracic aorta.

METHODS

We retrospectively retrieved the records of consecutive patients with degenerative thoracic aortic aneurysm of the aortic arch or descending aorta who underwent TEVAR between March 2007 and December 2014. Patients with a history of previous open or endovascular repair of the thoracic aorta, patients for whom preoperative thin-section computed tomography (CT) images were not acquired, those with a ruptured aneurysm or aneurysm $<$55 mm in diameter, and those with a common ostium of the supra-aortic arteries (such as the bovine arch) were excluded. This retrospective study was approved by the local Institutional Review Board, which waived the requirement for informed consent.

CT imaging protocol. Preoperative CT aortography was performed using a 64-slice CT scanner (Aquilion 64; Toshiba Medical Systems, Otawara-shi, Japan). Informed consent for CT scan was obtained from all patients before they underwent CT. Precontrast-enhanced chest CT was performed, and the images were reconstructed in 5-mm thickness without any overlap. Under the bolus-tracking mode with the region of interest at the ascending aorta, 90 mL of iodinated contrast medium was injected at a rate of 3.5 mL/s. When the density of the region of interest exceeded 150 Hounsfield units, the postcontrast-enhanced CT scan was initiated, starting from the lower neck and extending to the symphysis pubis. Postcontrast-enhanced images were reconstructed in 1-mm thickness at 0.8-mm intervals and were transferred to a workstation (Aquarius iNtuition, version 4.4.11.265; TeraRecon Inc, Foster City, Calif).

Centerline extraction and export. Two radiologists (C.K.C. and H.P.C.), with 14 years and 11 years of experience, respectively, in radiology and 10 years and 7 years of experience, respectively, in cardiovascular imaging with the postprocessing workstation used in this study, independently extracted the central luminal line (referred to as the centerline hereafter) of the aortic lumen semiautomatically and adjusted each of the extracted centerlines to be as close as possible to the center of the lumen. The path lengths along the centerline starting from the sinotubular junction to the innominate artery (INA), left common carotid artery (LCCA), left subclavian artery (LSCA), and celiac artery were measured and recorded. The midascending thoracic aorta (MATA) was defined as the midpoint along the centerline between the sinotubular junction and INA. The isthmus was defined as the site 2 cm distal to the LSCA along the path, and the mid-descending thoracic aorta (MDTA) was the midpoint along the path between the isthmus and celiac artery. Both radiologists were blinded to each other's results while measuring these parameters. We then exported the points along the centerline at 1-mm intervals with the spatial coordinates of each point in the three-dimensional x, y, and z planes.

Tortuosity index. Using the exported centerline data, the tortuosity indices of the thoracic aorta from the INA to MDTA were calculated by dividing the distance along the centerline (ie, the path length) between the INA and MDTA by the straight distance between the INA and MDTA, calculated using the coordinates of the arteries (Fig 1). The tortuosity indices of the aortic segments between the MATA and MDTA, the LCCA and MDTA, and the LSCA and MDTA were also calculated.

Centerline angle. By using the exported coordinates of the points along the centerline, the angles of the centerline (θ) at the supra-aortic arterial orifices (INA, LCCA, and LSCA) were calculated (Fig 2).[7] The vectors between the point at the orifice of the branch and the points at 15 mm proximal and distal to the branch were denoted a and b, respectively, and $||a||$ and $||b||$ denoted the magnitude of the vectors a and b, respectively. Angle θ was calculated using the dot product of the two vectors $a \cdot b = ||a||||b||\cos(\theta)$. The centerline angle at the MDTA was also calculated.

Fitting circle diameter. By using electronic calipers, two circles were fitted over the lesser and greater curvatures of the aortic arch[4] by two radiologists (C.K.C. and H.P.C.)