Image Postprocessing

Geometric measurements on axial source data can lead to inaccurate findings at angled vessel sections [12] (Fig. 1). Both MPR and centerline analysis are postprocessing techniques that enable precise determination of the aortic anatomy or pathology by adjusting the viewing plane perpendicularly to the vessel course. The major differences between software applications providing those functions comprise specific features of the single algorithm and design of the user interface. For this article, three commercial postprocessing workstations were used: 3viseon 3D Imaging Workstation (version 3.0.974.2, 3mensio Medical Imaging BV), Aquarius Workstation (version 3.6.2.3, TeraRecon, Inc.), and Vitrea Software (version 3.9.0.1, Vital Images, Inc.).

Centerline Analysis

Semiautomatic centerline analysis consists of computational detection of the geometric vessel centroid and subsequent identification and segmentation of the whole vessel lumen [3]. The purpose of this article is to illustrate the workflow as well as the benefits and limitations of centerline analysis of aortic CTA compared with MPR.

Imaging Requirements

Successful postprocessing of angiographic data necessitates image acquisition of adequate quality [7]. First, high spatial resolution with a reconstructed slice thickness not exceeding 1 mm and overlapping increment is essential to minimize partial volume effects and step artifacts during image reformation [8]. Second, optimal timing of contrast material injection is required to achieve sufficient and homogeneous enhancement of the arterial vasculature and to avoid streak artifacts from nearby veins [9–11].

OBJECTIVE. The purpose of our study was to illustrate workflow, benefits, and limitations of centerline analysis compared with double oblique multiplanar reformations using aortic CT angiography data.

CONCLUSION. Semiautomatic centerline analysis is beneficial for the assessment of aortic geometry and allows precise measurements of aortic diameters and lengths. It can be simple, fast, and reproducible, but it should be used with care considering its inherent limitations. Manually adjusted multiplanar reformations remain an essential tool for intuitive visualization of the vascular anatomy.
Second is automatic calculations. The software calculates the centerline connecting the predefined seed points, computes cross-sectional image planes perpendicular to the vessel course, and segments the vessel by determination of the lumen boundaries.

Third is visualization and manual editing. Centerline calculation and vessel segmentation should be verified on underlying source data. Manual editing should be used carefully because it involves individual errors.

Fourth is display of centerline calculation and measurements. Maximum, minimum, and mean diameters are automatically indicated on cross-sectional image planes. Additional length measurements can be performed manually.

Editing the Centerline

Each workstation offers different possibilities for controlling and correcting centerline analysis and initial segmentation results. Control points along the centerline are displayed in the three basic imaging planes and can be shifted if they are not located at the cross-sectional aortic centroid (Fig. 2). This is mandatory because deviation from the luminal center can lead to different diameter measurements. Automatic vessel boundary detection may require manual optimization, especially in cases of irregular vessel contrast, close relationship to another vessel with similar density, or ellipsoidal vessel lumen (e.g., aortic dissection [Fig. 3]). Segmentation of the vessel lumen can be improved by adjusting the upper and lower density thresholds or by adapting the degree of roundness of the segmented aortic lumen (Fig. 3). The lumen boundary at a single cross-section may be manually corrected with a freehand drawing tool.

Display of Centerline

Minimum, maximum, and mean diameters of the segmented lumen are displayed automatically on cross-sectional image planes reformatted perpendicularly to the centerline. Thus, the cross-sectional geometry can be determined quickly in any given segment. Furthermore, length measurements can be easily performed along the centerline.

Multiplanar Reformation

MPR enables the user to interactively generate an arbitrarily angled cross-section without distortion and loss of information. The problem-oriented target view is adjusted by manual manipulation of the transverse, coronal, and sagittal basic planes (Fig. 4). Precise quantitative analysis of both lumen and vessel wall requires an orientation exactly perpendicular to the vessel course and correct window leveling [13]. Moreover, MPR can serve to intuitively illustrate aortic abnormalities and their relation to vessel branches (Fig. 5).

Preoperative Planning of Endovascular Aortic Repair

One of the most important applications of the presented image postprocessing techniques is preoperative planning of endovascular aortic repair. If a patient is selected for endovascular aortic repair in favor of open surgery, careful preoperative procedure planning is necessary. Preoperative assessment includes depiction of anatomy and pathology as well as quantitative analysis. Necessary measurements are length and diameter of the pathology, distances between the pathology and aortic branches, as well as diameters at the target proximal and distal landing zones. Most often, all measurements can be easily performed using centerline analysis. However, MPR remains essential in cases in which centerline analysis is not possible, as discussed later. On the basis of the measurements, the appropriate endograft is selected with respect to type, diameter, length, and number of devices. Figures 6–8 illustrate preoperative length measurements and device selection and directly compare MPR with centerline analysis.

Discussion

Centerline analysis and MPR are essential vascular analysis tools that are especially appropriate for preoperative planning of endovascular aortic repair. In principle, both techniques offer the functionality of diameter and length measurements [14]. However, length measurements using MPR must be performed by assembling multiple straight measurements (Figs. 6–8), which may be time-consuming and, most notably, inaccurate. Measurements keeping reliably to the centerline are only possible using centerline analysis. In this way, the longitudinal dimensions of vascular lesions, such as aortic aneurysms (Fig. 6), and of the aortic segment proximal to the primary entry tear of type B aortic dissections can be assessed precisely (Fig. 7). However, length measurements along the centerline must always be critically evaluated because implanted endografts may follow a different route, as for example along the outer wall of a curved aneurysm [15].

The determination of aortic length is of paramount importance for the characterization of endograft landing zones (Fig. 8) as well as for determination of distances between the pathology and aortic branches (Figs. 6–8). Because aortic lumen segmentation is part of the centerline generation, centerline analysis enables fast determination of diameters at any given segment with high interobserver agreement [6]. In contrast, assessment of aortic diameters using MPR requires careful adjustments of imaging planes before measuring. Because this process is user-dependent, it may result in different measurements by different readers.

Improved reproducibility of measurements using centerline analysis is particularly helpful for comparison of long-term follow-up CTA because geometric changes may be reliably detected by different readers. However, this must be verified in larger long-term studies.

Note that centerline analysis has several limitations. Although it is usually performed easily and fast, the technique should only be used with an awareness of the associated limitations. To begin with, centerline analysis is not successful in all cases. Especially in complex disorders such as aortic dissections or distinct aortic kinking, the centerline calculation may fail or may result in inaccurate segmentation. If scan quality is low—for example, because of insufficient contrast—semiautomatic segmentation may fail [9]. Thus, segmentation results should always be visually checked, carefully edited if necessary, and used only if they are considered accurate. Furthermore, the correct orientation of the cross-sectional images cannot be adequately verified. Vessel analysis software solutions have not yet provided the possibility of visualizing the position and orientation of the computed cross-sectional image planes on the three basic imaging planes. Therefore, one is not able to adequately check whether the calculated cross-sectional images are actually perpendicular to the vessel course. Cross-sectional images that are inclined against the vessel course would generate artificially enlarged cross-sectional areas and vessel diameters.

A further limitation of centerline analysis lies in the type of visualization, which should be well considered when performing measurements. Depending on the vendor-specific user interface, the centerline itself can generally be visualized in two ways: stretched view (Fig. 9A) and curved view (Fig. 9B). A stretched view is a straightened view on the actually crooked vessel and offers a good survey of...
vessel anatomy and pathology. However, the process of artificial stretching will eliminate any information about vessel tortuosity, which may cause significant errors in the length measurements if they are performed not at the centerline but at the lumen boundary and in false preoperative planning for endovascular repair. Figure 10 shows this error in a simplified normal aortic arch (tortuosity, 10°/cm = radius of 5.73 cm and vessel diameter of 3 cm) in which all distances are computed between the same cross-sectional planes. The distances calculated along the outer and inner curvature differ by 26% from the distance calculated along the centerline. This may be of clinical significance because length measurements at the inner curvature of the aortic arch may be favored over the centerline in procedure planning of thoracic endovascular repair. Curved views may occasionally not provide such a good overview compared with a stretched view (Fig. 9), but they clearly depict the length differences between centerline and vessel boundary.

MPR is the alternative choice for unsuccessful centerline analysis because it does not involve any automatic computations. However, adequate adjustments of MPR require a certain expertise and familiarity with double oblique imaging planes. Even experienced radiologists may need several minutes to obtain the desired imaging plane. This is due to the time-consuming but often necessary process of repeated perpendicular adjustments at various aortic segments.

**Conclusion**

By enabling reproducible length and diameter measurements, centerline analysis provides fast characterization of aortic disease and has emerged as an outstanding tool for indication and planning of vascular interventions. Drawbacks of this technique are its limited verifiability and its dependence on the quality of vessel segmentation, which may be impaired in cases of complex anatomy or low image quality. MPR not only constitutes an alternative for unsuccessful centerline analysis but also offers the function of adjusting intuitive overviews on vascular peculiarities without distorting the actual anatomy.

**References**


(Figures start on next page)
Fig. 1—68-year-old woman with thoracoabdominal aortic aneurysm. Comparison of measurements of aortic diameters on axial source image (B) and centerline analysis (C).
A. Volume-rendered image illustrates pathology and location of performed measurements (arrow).
B. Measurement on axial source image results in inaccurate values because image plane is not adjusted perpendicular to course of aorta.
C. Measurement on cross-sectional image plane perpendicular to centerline.

Fig. 2—Centerline analysis in 66-year-old man with thoracoabdominal aortic aneurysm.
A–C. Control segmentation points of centerline are displayed in three basic imaging planes and can be moved if they seem not to be located in center of lumen.
Aortic CT Angiography

Fig. 3—Centerline analysis in 61-year-old man with aortic type B dissection.
A, Automatic algorithm for detection of lumen boundary using standard software settings is inaccurate because of ellipsoid true lumen of aortic dissection.
B, Accurate segmentation results are obtained by predefining lower degree of roundness for lumen. Note: Diameters provided by centerline analysis (green) must meet centerline. Therefore, maximum diameter is incorrect in this special case. Red line represents visually correct maximum diameter based on manual measurement.

Fig. 4—Double oblique multiplanar reformation (MPR) in 68-year-old woman with thoracoabdominal aortic aneurysm (same patient as in Fig. 1).
A–C, Orientation of two basic image planes is changed to generate MPR perpendicular to vessel course (C) similar to Figure 1C and in contrast to Figure 1B. In C, measurement of aortic diameters shows comparable results to centerline analysis (Fig. 1C).

Fig. 5—79-year-old man with aortic arch aneurysm and abdominal aortic aneurysm. Parasagittal plane based on double oblique multiplanar reformation visualizes aneurysm and its relation to supraaortic arteries. 1 indicates right atrium; 2, left atrium; 3, right pulmonal artery.
Fig. 6—61-year-old man with thoracic aortic aneurysm scheduled to undergo endovascular aortic repair. Double oblique multiplanar reformation (MPR) and centerline analysis for treatment planning are shown.  
A, Preoperative volume-rendered image provides good overview of pathology and its location to adjacent vessels.  
B, Length measurements (in mm) on MPR along vessel course. Green indicates length of aneurysm; dark blue, length of partially diseased aorta not suited for endograft deployment; yellow, distance between left subclavian artery (LSA) and beginning of partially diseased aorta; light blue, distance between left common carotid artery and beginning of partially diseased aorta; red, distal landing zone.  
C, Length measurements (in mm) corresponding to B performed along semiautomatically calculated centerline. Note that distance between LSA and lesion (10.96 mm) is too short for adequate proximal landing zone for endograft. Minimum overall length of necessary endograft system can be calculated for this patient as follows: minimum proximal landing zone (20 mm) + partially diseased aorta (32.42 mm) + aneurysm length (90.41 mm) + minimum distal landing zone (20 mm) = 162.83 mm.  
D, Result shown on volume-rendered image after endovascular aortic repair. Transfemoral implantation of two endografts with length of 150 mm each (overlap of 40 mm) and overstenting of LSA achieved stable endograft fixation at healthy aortic segment.
Aortic CT Angiography

Fig. 7—65-year-old man with aortic type B dissection scheduled to undergo endovascular aortic repair. Double oblique multiplanar reformation (MPR) and centerline analysis for treatment planning are shown. Endovascular aortic repair of aortic type B dissections requires sealing of primary entry tear.

A, Preoperative volume-rendered image provides good overview of lesion.

B, Manual length measurements (in mm) on MPR. Dark blue indicates distance between left subclavian artery (LSA) and primary entry tear; red, distance between LSA and beginning of diseased aorta; light blue, length from left common carotid artery distal to LSA.

C, Length measurements (in mm) corresponding to B performed along centerline using centerline analysis. As is often the case in aortic type B dissections, distance between LSA and beginning of dissection (15.43 mm) is too short for endograft deployment, making it necessary to overstent LSA.

D, Result shown on volume-rendered image after endovascular aortic repair with transfemoral implantation of two endografts (each with length of 150 mm). Note transposition of LSA to left common carotid artery.
Fig. 8—59-year-old woman with infrarenal abdominal aortic aneurysm scheduled to undergo endovascular aortic repair. Double oblique multiplanar reformation (MPR) and centerline analysis for treatment planning are shown.

A, Preoperative volume-rendered image provides good overview of pathology.
B, Manual length measurements (in mm) on MPR. Often it is not possible to create MPR showing entire pathology and all relevant adjacent structures. Dark blue indicates length of aneurysm; green and red, distances between right and left renal arteries (RRA, LRA) to beginning of aneurysm.
C, Length measurements (in mm) corresponding to B performed along centerline using centerline analysis. Note that healthy aortic segment distal to RRA (14.35 mm) is too short for adequate endograft landing zone.
D, Result of endovascular aortic repair with transfemoral implantation of bifurcated endograft system shown on volume-rendered image. Note fixation with uncovered bare springs beyond RRA ostium and inferior to left renal artery.
Aortic CT Angiography

Fig. 9—Centerline analysis in 68-year-old man with aortic arch aneurysm (red arrow).
A, Stretched view of centerline appears as if vessel had been pulled straight and sliced lengthwise. It provides good overview of pathology and vessel course by clearly showing location of pathology and tapering of aorta. Red line represents centerline; blue line, perpendicular cross-section at aneurysm center. BC = brachiocephalic trunk, LCA = left common carotid artery, LSA = left subclavian artery.
B, Curved view of centerline gives relatively undistorted view of vessel course and shows relation of analyzed vessel to surrounding structures. Furthermore, it clearly depicts length differences between centerline and inner and outer curvature of vessel boundary. Yellow line represents centerline; red line, perpendicular cross-section at aneurysm center corresponding to blue line in A. SVC = superior vena cava.
C, Curved view from B is rotated to show that curved view can sometimes be confusing compared with stretched view (A) because parts of ascending aorta and aortic arch are displayed twice. Yellow line indicates centerline.

Fig. 10—Graph of simplified normal aortic arch with three branches. Dotted line shows centerline, solid lines indicate inner and outer curvature.
A, Illustration of normal anatomy: curvature, 10°/cm = radius of 5.73 cm (long arrow) and aortic diameter of 3 cm (short arrow).
B, Part of aortic arch between two cross-sectional planes shown in A is straightened without distorting inner and outer curvature to illustrate difference by 26% (1.57 cm) between distance calculated along outer curvature (7.57 cm) and distance calculated along centerline (6.0 cm).
C, Part of aortic arch between two cross-sectional planes shown in A illustrated as stretched view to show associated distortion. Stretched views result in lengthened inner curvature and shortened outer curvature, including distances between supraaortic arteries, by 26%.