How to Measure the Aorta Using MRI: A Practical Guide

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ARTIC DIMENSIONS ARE IMPORTANT in the risk assessment of aortic pathology, aneurysms, dissection, and rupture. However, there is much debate on how, when, and where to measure the aorta. The main imaging techniques used to measure the aorta are transthoracic echocardiography (TTE), computed tomography (CT), and magnetic resonance imaging (MRI). MRI has the advantage over TTE and CT in that it is able to accurately visualize the entire aorta without using ionizing radiation and is able to give additional information on ventricular, valvular and vascular function and flow dynamics. Proximal aortic diameter measurements can vary up to 5 mm between imaging modalities, which can lead to relevant differences in clinical decisions about preventive surgery. The American and European guidelines give recommendations on how to measure the aorta, but these recommendations differ and can be ambiguous. There are limited MRI guidelines on how to measure the aorta. Accordingly, still large variations exist in image acquisition and analysis in MRI. The question is: how, when, and where do the guidelines advise us to measure the aorta? We will discuss aortic analysis in MRI and compare these to accepted practice in CT and TTE. This article provides recommendations for clinicians on aortic measurements in the adult population using MRI, with an emphasis on the thoracic aorta.

How, When, and Where to Measure

How: With or Without Aortic Vessel Wall?

The normal ascending aortic vessel wall is ~2 mm thick, so inclusion of the wall can account for a 4-mm difference in aortic size. Echocardiography guidelines recommend the leading edge-to-leading edge (L-L) method (Fig. 1a) for measuring aortic diameters; consequently, the L-L method has been used in many trials that defined normal aortic size limits. Studies comparing multimodality imaging techniques have shown that the inner edge-to-inner edge (I-I) method (Fig. 1b–d) for MRI is in best agreement with the L-L method of echocardiography. Given the high conformity with echocardiographic measurements and that with bright-blood MR angiography (MRA) techniques, only the equivalent of I-I measurements are obtained, and it

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would be advisable to use the I-I method in MRI. In the case of wall thickening or aneurysm formation using the I-I method, the external diameter should also be reported, as it aids in surgical or transarterial intervention planning (Fig. 2a–f).4,7 For the outer–outer measurements, black-blood images are required. For image acquisition, MRI provides multiple possibilities to obtain luminal enhancement. Gadolinium contrast-enhanced images can provide high-resolution images of aortic lumen; however, when possible it is advisable to avoid application of contrast medium.2 If prolonged imaging is required noncontrast-enhanced imaging techniques can be used, such as: black-blood (using fast spin-echo), bright-blood (using time-of-flight, phase-contrast or steady-state free-precession [SSFP]), water-fat separated 3D-imaging or 4D-flow imaging.1,8 It is advisable to use the same acquisition technique during follow-up to aid measurement consistency. Table 1 provides an overview of recommendations for hardware as well as main sequence characteristics.

**How: Which Diameter to Report?**

Measurement of the aorta should ideally be performed in a 3D dataset using a double-oblique angulation perpendicular to the vessel long-axis.1,4 With new automated software, double-angulation is decreasingly time-consuming and therefore is recommended whenever available as standard of care.1 Measurements can also be performed in standard 2D axial, coronal, and sagittal orientation, which have been shown to give an accurate assessment of aortic disease.8 A practical and efficient strategy can be to measure aortic diameters using axial, coronal, and sagittal orientations as first assessment before double-oblique measurement of the maximal and minimal diameter for optimal measurement accuracy. If previous scans are available, a side-by-side comparison with the oldest scan is crucial to get the most sensitive comparison. For side-by-side comparison, measurement location is arbitrary as long as the same locations and techniques are used in both the new measurement as well as remeasurement of the previous scan. The used measurement technique and location should always be reported.

**When: Timing in Cardiac Cycle?**

Echocardiography guidelines recommend that all aortic measurements except for the annulus should be performed during diastole.9 The European Society of Cardiology (ESC) guideline does not give specific recommendations; however, diastolic images
give the best reproducibility because aortic pressure is the most stable and the proximal aorta shows less motion during diastole.\textsuperscript{3}

In the American College of Cardiology / American Heart Association (ACC/AHA) and societal MRI guidelines, it is specified that electrocardiogram (ECG) gating should be performed at end-diastole.\textsuperscript{2,7} In conclusion, for the acquisition of the aorta using MRI it is advisable to use ECG-gating triggered to end-diastole, with an additional short stack of SSFP cines parallel to the valve through the left ventricular outflow tract for systolic measurement of the annulus (Fig. 1b) and end-diastolic average cusp-to-commissure and largest cusp-to-cusp measurement of the sinus (Figs. 1c, 2c).

**Where: Anatomical Landmarks**

Figure 3 shows the recommended anatomical landmarks to measure the aorta.
Reference Values and Follow-Up

MRI is ideal for follow-up of aortic dimensions due to its capacity to image the entire aorta without using radiation or contrast. A normal reference range is imperative in the diagnosis and prognosis of aortic disease and in the timing of surgical interventions. MRI aortic reference values are available in a limited number of studies and differ in measurement and acquisition techniques, emphasizing the need for larger reference studies and updated guidelines. Although aortic diameters are highly correlated with body surface area, the guidelines still mainly use nonindexed diameters for timing of follow-up and surgical intervention. A short overview of follow-up imaging frequency in aortic disease is shown in Table 2.

Future Perspectives

Better predictors of aortic dissection are needed, where the International Registry of the Aortic Dissection showed that >50% of dissections occurred at diameters below the cutoff for preemptive surgery. In this respect, MRI will take a predominant place in the diagnostic assessment of aortic pathology, where it is the only technique available to image...
the entire aorta with additional information on physical properties like distensibility, stiffness, wall shear stress, and blood flow patterns. Other geometric parameters like aortic length, cross-sectional area, tortuosity, and volumetric measurements have been proposed as potentially more sensitive risk factors for aortic dissection. With the rise of artificial intelligence, it is expected that all these parameters can be generated with minimal or no input required. However, first a clear definition of how to measure the aorta is needed to create reliable input for deep-learning training. Therefore, it is crucial to create uniformity by widely accepting MRI guidelines on how, when, and where to measure the aorta. The main recommendations provided in this article are summarized in a flowchart (Fig. 4).
TABLE 2. Imaging Follow-Up in Thoracic Aortic Disease1-3,8

| Clinical situation | Follow-up |
|--------------------|-----------|
| Aortic aneurysm    | Aorta >40 mm: annual or biannual MRI/CT depending on aortic dilatation progression and family history |
|                    | Aorta >45 mm: annual or biannual MRI/CT |
| Bicuspid valve     | Normal aortic dimensions: MRI/CT every 3 to 5 years |
|                    | Aorta >40 mm: annual or biannual MRI/CT depending on aortic dilatation progression and family history |
|                    | Aorta >45 mm: annual or biannual MRI/CT |
| Marfan’s syndrome  | MRI at baseline and MRI/CT every 3 years; |
|                    | TTE annually if aortic diameter is stable <45 mm and negative family history of aortic dissection. >45 mm: annual or biannual MRI/CT |
| Loehys-Dietz syndrome | Annual MRI from brain to pelvis |
| Turner syndrome    | Normal baseline measurement: MRI/CT/TTE every 5 to 10 years or preconception |
| Acute aortic dissection | TTE and MRI/CT at 1, 3, 6, and 12 months, then annual TTE and MRI/CT |
| Chronic aortic dissection | TTE and MRI/CT every 2 to 3 years |
| IMH or PAU         | MRI/CT at 1, 3, and 6 months, then annual MRI/CT |

*Selection of imaging modality for follow-up is multifactorial, depending on imaging requirements, risks, and availability. It is desirable to use the same imaging modality over time to aid measurement consistency.

CT: computed tomography; IMH: intramural hematoma; MRI: magnetic resonance imaging; PAU: penetrating atherosclerotic ulcers; TTE: transthoracic echocardiography.

FIGURE 4: Flowchart summarizing the provided recommendations.

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