Three-Dimensional Understanding of Complexity of the Aortic Root Anatomy as the Basis of Routine Two-Dimensional Echocardiographic Measurements

Shumpei Mori, MD, PhD; Yu Izawa, MD; Shinsuke Shimoyama, MD; Justin T. Tretter, MD

Background: Because the aortic root anatomy is too complicated to evaluate only with 2D methodology, precise appreciation of its 3D anatomy is a prerequisite for all cardiologists and cardiac surgeons.

Methods and Results: We provide comprehensive image panels reconstructed from CT datasets to understand the complexity of the aortic root by focusing on the representative longitudinal sections cut through the central zone of coaptation.

Conclusions: The provided images will accelerate profound understanding of the 2D long-axis image of the aortic root commonly interrogated with 2D echocardiography, as well as correlated clinical measured values, including the geometric height, effective height, and coaptation length.

Key Words: Anatomy; Aortic root; Computed tomography

Figure 1. Computed tomographic images showing 3D anatomy of the aortic root. Transparency of the volume-rendered images of the aortic root (A, B) is increased (C-F) to reveal the 3D morphology of the zone of coaptation with the central point located inferior relative to the sinotubular junction (red dotted lines), and to reveal the location and morphology of the hingelines of the aortic leaflets taking the shape of a 3-pronged coronet (G, H). Yellow, red, and green circles indicate the 3 nadirs of the hingelines of the right, left, and non-coronary aortic leaflets, respectively. Virtual basal ring plane created by connecting the 3 nadirs of the hingelines is projected in the yellow-green dotted lines. The upper panels (A, C, E, G) are images viewed from the ascending aorta. The lower panels (B, D, F, H) are images viewed from the anterosuperior direction. L, left coronary aortic sinus; N, non-coronary aortic sinus; R, right coronary aortic sinus.
Figure 2. Computed tomographic images showing various center planes of the aortic root orthogonal to the virtual basal ring plane. (Top panels) Volume-rendered images of the aortic root viewed from the ascending aorta to show how the corresponding inferior orthogonal panels are created. The aortic root is sectioned along each yellow dotted line and viewed from the direction indicated by each white arrow (A-I). (A-C) 2D center planes created using multiplanar reconstruction method. Any center planes, cut through the central zone of coaptation, can provide the precise and shortest coaptation length (CL). This central zone of coaptation is located significantly inferior to the plane of the sinutubular junction (red dotted lines). The CL measured in an off-center fashion (C) is significantly longer than the precise CL measured using center planes (see also Figure 3). Because any of the single center planes cannot cut through both nadirs of the hingelines of the 2 sectioned leaflets (A–C), which is necessary to determine the location of the virtual basal ring plane, the virtual basal ring plane (yellow-green dotted lines) determined from common multiplanar reconstruction methods needs to be projected on every panel. To measure the precise effective height (EH), both the center plane and projected virtual basal ring plane are required (B). The plane of the sinutubular junction is usually not parallel to the virtual basal ring plane because the size of each sinus varies significantly. (D–F) Fused images of 2D and 3D reconstructions. (G–I) 3D volume-rendered images. The left-hand column (A, D, G) shows the center plane sectioning both non- and left coronary aortic sinuses and leaflets in equal fashion. Although this image provides the familiar 2D aspect of the aortic root (A) used in many schemes, a significant distance between the projected virtual basal ring plane and the 2 viewed leaflet hinges is appreciated (A), as the hinges viewed in this plane will never be nadirs of the hingelines of the 2 sectioned leaflets. The middle column (B, E, H) shows the center planes bisecting the left coronary aortic sinus and opposite coaptation zone. Precise measurement of the geometric height (GH) can only be performed using this plane, as the nadir of the hingeline of the left coronary aortic leaflet (red circles) is provided in this section. The right-hand column (C, F, I) shows the biplanar sectioned images cut through 2 of 3 zones of coaptation: L, left coronary aortic sinus; N, non-coronary aortic sinus; R, right coronary aortic sinus.
Aortic valve-sparing surgery is being increasingly used in patients with aortic regurgitation and/or proximal aortic aneurysm. Despite technical advances in echocardiography, the aortic root morphology is still assessed mainly using 2-dimensional (2D) echocardiography in clinical practice. However, the aortic root anatomy is too complicated to evaluate only with 2D methodology, so the need for 3D evaluation has increased to define the echocardiographic predictors of successful surgical repair. In this context, precise appreciation of the 3D anatomy of the aortic root is fundamental.

Our recent publication highlighted the significant limitation of 2D imaging by demonstrating the difference between the off-center planes and bisecting plane of the aortic root. Here, we extend our anatomical insight by demonstrating several comprehensive images reconstructed from computed tomographic (CT) datasets to enhance the importance of 3D understanding of the complexity of the aortic root anatomy as the basis of routine 2D echocardiographic measurements. The main advantage of echocardiography is functional and morphological evaluation with live recording in a blood pressurized dynamic state. Cardiac CT static images, also reconstructed from the blood-filled living heart, can provide complementary anatomical information with higher spatial resolution. The images, therefore, will enhance precise understanding of complexity of the aortic root anatomy.

There are 2 key features.
(1) The basal ring corresponding to the so-called “annulus” is no more than a virtual plane created by connecting the 3 nadirs of the hingelines of the individual aortic valve leaflets (Figure 1). It has no anatomical counterpart, and is located inferior to the anatomical ventriculo-arterial junction, and not parallel to the plane of sinutubular junction.
(2) The central coaptation zone is located significantly inferior to the plane of the sinutubular junction (Figures 1, 2). These subtleties were not sufficiently accounted for in the report by Hagendorff et al.

Based on these features, when evaluating any given 2D longitudinal image of the aortic root, the following 5 clinical implications should be appreciated.
(1) Only the off-center plane, which cuts through the nadirs of the hingelines of the 2 sectioned leaflets (nadir-nadir plane), can provide the accurate location of the virtual basal ring plane (Figure 3).
(2) Any center planes, cut through the central zone of coaptation, cannot provide the exact location of the virtual basal ring plane as they cannot cut through the nadirs of the hingelines of the 2 sectioned leaflets (Figure 2).
(3) Only the center plane bisecting the sinus and opposite zone of coaptation can cut through one of the 3
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coaptation length, are clinically important for both preoperative planning and postoperative evaluation of aortic valve-sparing surgery. It is time to revisit these values, commonly evaluated by 2D echocardiographic measurement, with reference to a more precise and reproducible method based on 3D evaluation.

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None.

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Thus, the 3D appreciation of the complexity of the aortic root anatomy is fundamental to understanding the 2D images. Furthermore, recognition of both the feasibility and utility, as well as the limitations, of the center planes is important. It is now common to evaluate living-heart anatomy three-dimensionally by using multiple imaging modalities. Any of the values, including the virtual basal ring diameter, geometric height, effective height, and coaptation length, are clinically important for both preoperative planning and postoperative evaluation of aortic valve-sparing surgery. It is time to revisit these values, commonly evaluated by 2D echocardiographic measurement, with reference to a more precise and reproducible method based on 3D evaluation.