ADULT

A comparison of aortic root measurements by echocardiography and computed tomography

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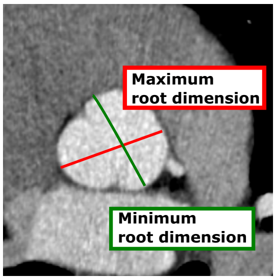
ABSTRACT

Objectives: The aim of the study is to evaluate an optimal way to assess the dimensions of the aortic root and each of the sinuses of Valsalva and examine how a single measurement in 1 plane (echocardiography or 2-dimensional computed tomography) can underestimate the maximum dimension of the aortic root.

Methods: Computed tomography and transthoracic echocardiography images of the aortic root and ascending aorta of 112 patients were analyzed. The minimum and maximum aortic root dimensions, the root perimeter, and the total area of all 3 sinuses of Valsalva were measured on a plane perpendicular to the long axis of the aorta using 3-dimensional multiplanar reconstruction. Moreover, the maximum root dimension was compared with the measurements obtained from the echocardiography and 2-dimensional computed tomography angiography measurements.

Results: The difference in the measurements of the minimum and maximum root dimension was 5.4 ± 3.2 mm (range, 0-21 mm, $P < .0001$) and was significantly larger in patients with bicuspid aortic valves compared with those with tricuspid valves (6.3 ± 4 mm, range, 0-21 mm vs 4.9 ± 2.6 mm, range, 0-15 mm, $P = .036$). The maximum root dimension measured in 3-dimensional multiplanar reconstruction (49.1 ± 9.0 mm) differed significantly from the root dimension measured in transthoracic echocardiography in the parasternal long-axis view (44.8 ± 8.4 mm) and 2-dimensional computed tomography (axial plane: 45.5 ± 9.0 mm, coronal plane: 46.1 ± 8.8 mm, sagittal plane: 45.1 ± 8.9 mm) ($P < .001$).

Conclusions: The difference in the measurements of the minimum and maximum aortic root dimensions is significant and may exceed 20 mm, especially in patients with bicuspid aortic valves. Therefore, aortic root dimensions can be significantly underestimated with the measurement (echocardiography, computed tomography angiography) performed in only 1 plane. (J Thorac Cardiovasc Surg 2019;157:479-86)



The difference between maximum and minimum aortic root dimensions.

Central Message

The difference between the minimum and maximum aortic root dimensions is significant. Aortic root dimensions can be significantly underestimated using echocardiography or 2D CT angiography.

Perspective

The dimensions of the aortic root assessed on the basis of the measurements performed in only 1 plane (sagittal, coronal, axial) or using echocardiography may be significantly underestimated. The evaluation of the maximum dimension of the aortic root should be done on the cross-section of the aorta, preferably using a 3D multiplanar reconstruction mode in CT or MRI.

See Editorial Commentary page 487.

The aortic root is the most complex segment of the human aorta. The cross-section of the aortic root is not circular. It is composed of 3 overlying ellipsoid sinuses of Valsalva that collectively describe a trilobal cross-section in the transaxial view.[1] The understanding of its detailed anatomy is essential when planning treatment for patients and an optimal surgical strategy.

According to the guidelines, echocardiography is the suggested method used to screen and evaluate the dimension of the aortic root, and in daily practice, almost

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Abbreviations and Acronyms

AHr = aortic root area/patient's height ratio
BAV = bicuspid aortic valve
CI = confidence interval
CT = computed tomography
ECG = electrocardiography
MRI = magnetic resonance imaging
TAV = tricuspid aortic valve
3D = 3-dimensional
2D = 2-dimensional
TTE = transthoracic echocardiography

Scanning this QR code will take you to the article title page to access supplementary information.

all patients qualified for cardiac surgery undergo this examination.[2,3] Computed tomography (CT) and magnetic resonance imaging (MRI) are usually performed in patients with a suspected pathology of the aorta, in the presence of a bicuspid aortic valve (BAV), in patients scheduled for minimally invasive surgery, and in other circumstances requiring the knowledge of the anatomy of the chest, heart, or aorta.

In most patients, the "aortic root dimension" is evaluated using transthoracic echocardiography (TTE) in the long axis.[2-4] However, this measurement can differ from the maximum aortic root dimension.[5,6] A subsequent underestimation of the maximum aortic root dimension can influence the physician's decision-making. In such a case, the patient may be offered suboptimal treatment, and in consequence, a dilated aortic root may be left untreated.

The aortic root is often asymmetric, and intuitively, its dimensions should be measured on a cross-section perpendicular to the long axis of the vessel. The anatomy of the aortic root has been well examined, but there are no data on the difference in the measurements of the minimum and maximum aortic root dimensions.[2,7-9] Obviously, the measurement performed in only 1 plane could significantly underestimate the maximum aortic root dimension (Figure 1). However, to date, the extent of the underestimation of such a measurement has not been examined. Even though the problem is clinically important and the solution seems to be evident, the phenomenon of the underestimation of the dimensions of the aortic root has not been evaluated so far. The difference in the measurements of the measured and maximum aortic root dimensions may not be a substantial problem for patients with a small root or an already large aneurysm but may be significant in patients with moderately dilated aortas.

The aim of the study is to precisely evaluate the dimensions of the aortic root using CT angiography and to assess whether there are significant differences in the measurements of the minimum and maximum aortic root dimensions. Moreover, the measurements obtained from the 3-dimensional (3D) multiplanar reconstructions of the CT angiography images were compared with the results from the echocardiography examinations and standard 2-dimensional (2D) CT angiography images.

PATIENTS AND METHODS

Patient Population

In total, the data from 206 patients who had CT angiography scans performed before cardiac surgery procedures were assessed. The CT angiography images were evaluated, and only those examinations in which the aortic root was properly visualized were included for analysis (no electrocardiography [ECG]-gated CT: N = 54 patients, poor-quality CT angiogram: N = 28 patients, not enough contrast in the aorta: N = 12 patients). Subsequently, the data from 112 patients were selected for final assessment. The demographic and biological data of the patients, including the gender, age, height, weight, presence of aortic valve pathologies, and hypertension, were collected.

MATERIALS AND METHODS

The ECG-gated CT angiography images with the slice thickness of 1.5 mm or less were evaluated by 2 independent observers with experience in the assessment of the CT angiography of the aorta. The analyses were performed using Horos software (GNU Lesser General Public License, Version 3.0, LGPL 3.0) in 3D double oblique multiplanar reconstruction mode in the end diastole. The dimensions of the aortic root, sinotubular junction, and tubular ascending aorta were assessed. The measurements were carried out on cross-sections on planes perpendicular to the long axis of the vessel (Figure 2). The planes crossed the widest parts of the examined aortic segments (ie, for the aortic root, the widest segment usually in the middle of the sinuses of Valsalva).

The following parameters were measured in all the patients: (1) the minimum aortic root dimension (corresponding to the minor axis of an ellipse); (2) the maximum aortic root dimension (corresponding to the major axis of the ellipse); (3) the dimensions of the root measured from the right, left, and noncoronary sinuses (cusp-commissure measurements); (4) the area of the cross-section of the root; and (5) the perimeter of the whole root. For each segment (root and ascending aorta), the measurements were performed on the same cross-section. The methodology of the measurements is shown in Figure 3.

The maximum root dimension was compared with the measurements obtained from the echocardiography (long-axis view) and standard 2D CT angiography (in each of the 3 planes: axial, coronal, and sagittal).

Statistical Analysis

The normality of data distribution was assessed using the Shapiro–Wilk test. The means were compared using the Student *t* test or the Mann–Whitney *U* test depending on the normality of the distribution. The distribution of categoric variables was compared using the chi-square test. The inter- and intraobserver variabilities were assessed using the interclass correlation coefficient. All analyses were performed using Dell Statistica 13 software (Dell, Round Rock, Tex). The study was approved by the local Ethics Committee of the Wroclaw Medical University.

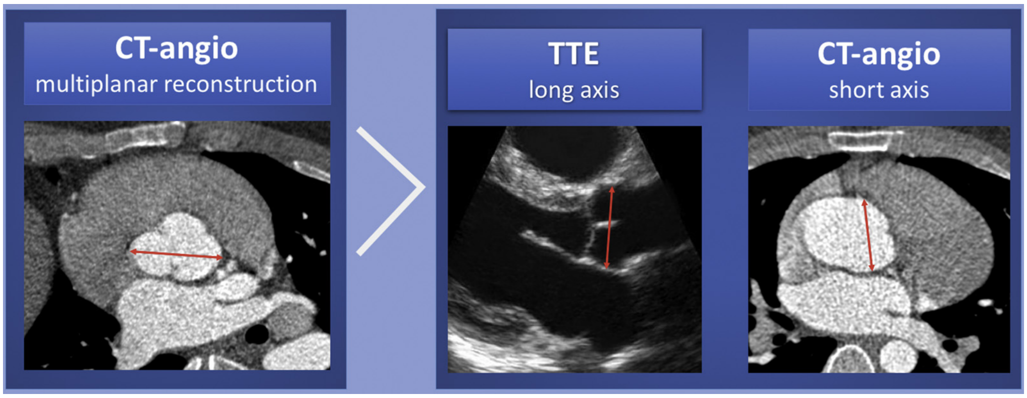


FIGURE 1. Underestimation of aortic root dimensions based on the method of the measurement. *CT*, Computed tomography; *TTE*, transthoracic echocardiography.

RESULTS

Demographic Data

A total of 112 patients were included in the final analysis. The age of the patients was on average 61 ± 15 years, and 69% were male. A total of 56% of the patients had aortic valve insufficiency, and 19% had aortic stenosis. Arterial hypertension was present in 63% of patients. The indications for surgery were as follows: primary aortic valve surgery ± aneurysm (81 patients, 72%), coronary artery bypass grafting (24 patients, 21%), mitral valve surgery (5 patients, 4%), and cardiac tumor (2 patients, 2%). Table 1 presents the clinical characteristics of the study population. BAVs were present in 36% of the patients. The comparison between the patients with BAV and tricuspid aortic valves (TAVs) is presented in Table 2.

Computed Tomography Angiography With 3-Dimensional Multiplanar Reconstruction

The maximum and minimum dimensions of the aortic root were on average 49.1 ± 9 mm and 43.6 ± 8.4 mm, respectively. The difference in the measurements of the minimum and maximum root dimension was on average 5.4 ± 3.2 mm (range, 0-21 mm; $P < .0001$). The dimension of the root measured from the right coronary sinus was 45.8 ± 9.3 mm, from the left coronary sinus was 46.7 ± 8.7 mm, and from the noncoronary sinus was 45.9 ± 9.1 mm.

The difference in the measurements of the minimum and maximum aortic root dimension did not correlate with the patient height ($r = 0.115$, $P = .115$), weight ($r = 0.029$, $P = .768$), and body surface area ($r = 0.079$, $P = .426$).

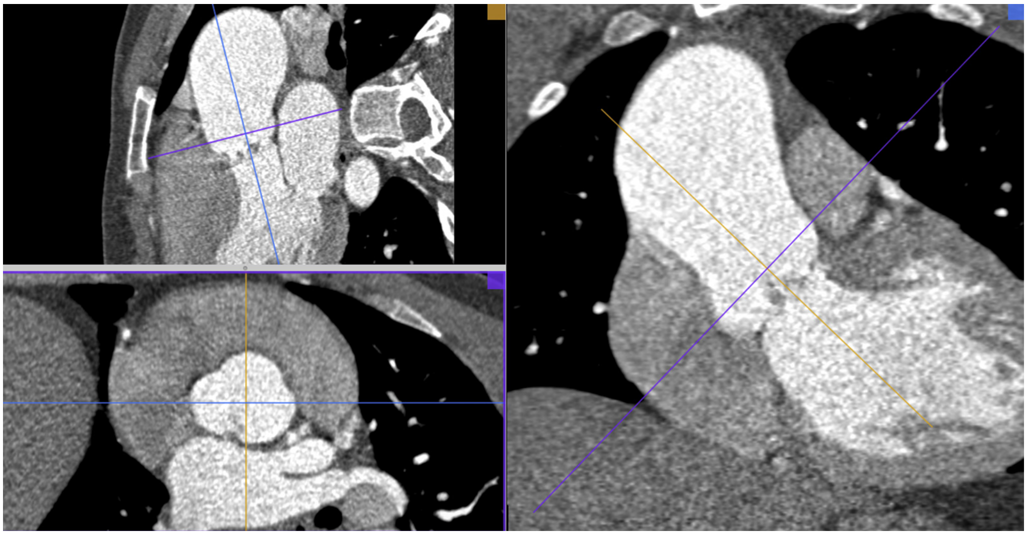


FIGURE 2. 3D reconstruction of the CT angiography image with the visualization of the aortic root on a plane perpendicular to the long axis of the aorta.

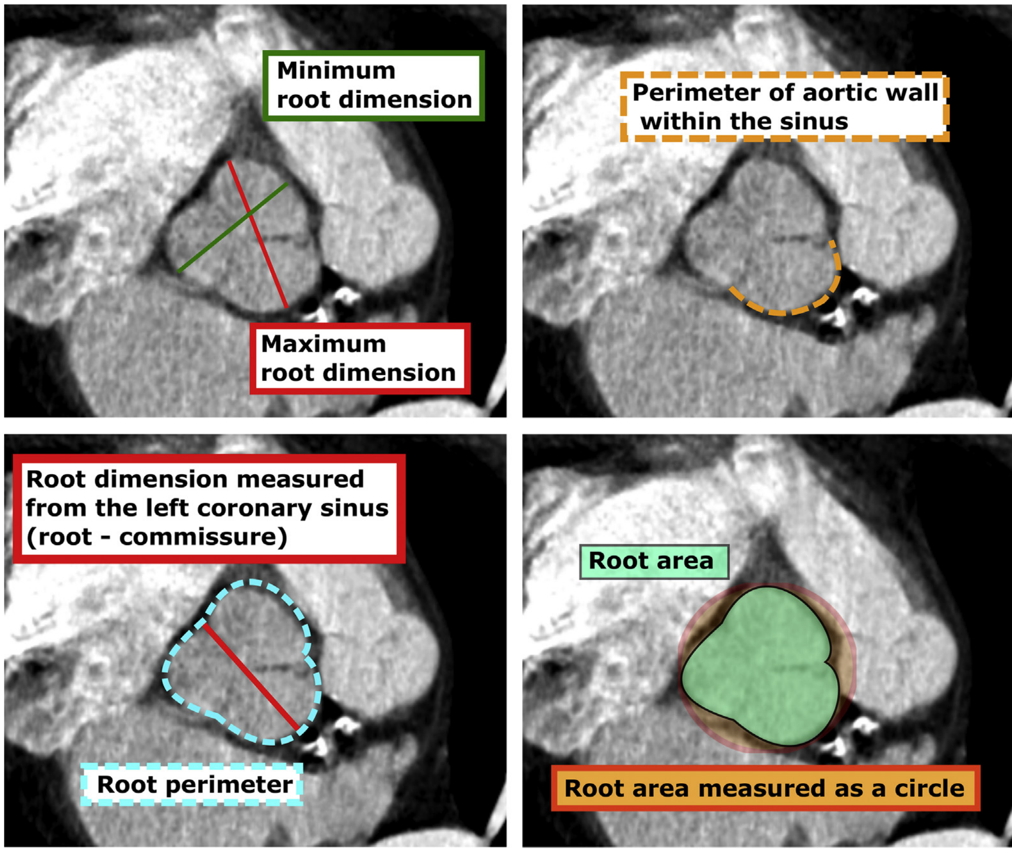


FIGURE 3. Measurements of the aortic root performed on a plane perpendicular to the long axis of the vessel using the CT angiography with 3D multiplanar reconstruction.

The difference in the measurements of the minimum and maximum aortic root dimension was 3.5 ± 2.6 mm (range, 0-9 mm) in patients with the maximum root dimension of less than 40 mm, 5.3 ± 2.6 mm (range, 1-11 mm) for aortic roots measuring 40 to 49 mm, 5.8 ± 3.7 mm (range, 1-21 mm) for aortic roots measuring 50 to 59 mm, and 7.3 ± 3.0 mm (range, 4-13 mm) for aortic roots 60 mm or more (Figure 4).

The number of patients diagnosed with an aneurysm (>50 mm) of the aortic root varied when the maximum and minimum root dimensions were used. The aneurysm was diagnosed in 49 patients (43%) when the maximum root dimension was taken into account and in 23 patients (21%) when the minimum root dimension was used.

The perimeter of the aortic root was on average 152.5 ± 29.2 mm (left coronary sinus: 49.1 ± 9.8 mm; right coronary sinus: 52.4 ± 12.6 mm; noncoronary sinus: 54.9 ± 12.5 mm). The ratio of the perimeter of the aortic wall within the sinus of Valsalva to the total perimeter of the root was 31.6% ± 3.4% (95% confidence interval

TABLE 1. Characteristics of the patients

Parameters	All patients (n = 112)	Male (n = 78)	Female (n = 34)	*P* value*
Age (y)	61.3 ± 14.8 (range, 19-83)	59.2 ± 15.1 (range, 19-81)	66.2 ± 13 (range, 29-83)	.026
Height (cm)	170.5 ± 9.7 (range, 148-200)	174,7 ± 7.7 (range, 158-200)	160.9 ± 6.4 (range, 148-176)	<.001
Weight (kg)	80.9 ± 14.4 (range, 15-122)	84 ± 13.8 (range, 56-120)	73.8 ± 13.3 (range, 56-122)	.001
Body mass index (kg/m^2)	27.9 ± 4.4 (range, 16.4-45.4)	27.6 ± 4 (range, 16.3-37.8)	28.5 ± 4.9 (range, 22.1-45.4)	.288
Body surface area (m^2)	1.92 ± 0.19 (range, 1.5-2.42)	1.99 ± 0.17 (range, 1.7-2.43)	1.77 ± 0.15 (range, 1.5-2.23)	<.001
Hypertension	70 (63%)	52 (67%)	18 (53%)	.333
BAV	40 (36%)	29 (37%)	11 (32%)	.624
Aortic insufficiency	63 (56%)	44 (56%)	19 (56%)	.933
Aortic stenosis	21 (19%)	17 (22%)	4 (12%)	.181

BAV, Bicuspid aortic valve. **P* value is comparison between male and female patients.

TABLE 2. Characteristics of patients with tricuspid and bicuspid aortic valves

Parameters	Tricuspid aortic valve (n = 72)	Bicuspid aortic valve (n = 40)	*P* value
Age (y)	64 ± 14.1 (range, 22-83)	56.7 ± 15.1 (range, 19-80)	.016
Male patients	49 (68%)	29 (73%)	.62
Height (cm)	169.8 ± 10.4 (range, 150-200)	171.5 ± 8.4 (range, 148-185)	.394
Weight (kg)	80.7 ± 15.3 (range, 56-122)	81.3 ± 12.9 (range, 56-115)	.848
Body mass index (kg/m^2)	28 ± 4.6 (range, 17.5-45.4)	27.6 ± 3.9 (range, 16.4-37.1)	.716
Body surface area (m^2)	1.92 ± 0.2 (range, 1.5-2.43)	1.94 ± 0.17 (range, 1.58-2.29)	.602
Hypertension	48 (67%)	22 (55%)	.007
Aortic insufficiency	44 (61%)	19 (48%)	.122
Aortic stenosis	7 (10%)	14 (35%)	.001

[CI], 29.4-41.0) for the left coronary sinus, 33.4% ± 3.3% (95% CI, 28.0-39.0) for the right coronary sinus, and 35.0% ± 3.7% for the noncoronary sinus (95% CI, 31.8-44.3) (Figure 5).

The area of the cross-section of the aortic root was 17.3 ± 6.3 cm^2. It differed significantly from the root area measured as a circle (19.2 ± 7.1 cm^2, $P < .001$), where the radius was half of the maximum root diameter (πr^2, π*(maximum diameter/2)^2). The maximum diameter of the tubular ascending aorta was 50.6 ± 10.5 mm. The data are presented in detail in Table 3.

All parameters, except for the perimeter of the aortic wall within the left coronary sinus, were significantly larger in men than in women. The data are presented in detail in Table 3.

Bicuspid Versus Tricuspid Valves

The maximum dimension of the aortic root and ascending aorta did not differ significantly between patients with BAVs and TAVs. In 50% of patients with BAV and TAV, the difference in the measurements of the maximum and minimum aortic root dimensions was 5 mm or larger (Figure 6). This difference was significantly larger in patients with BAVs (6.3 ± 4 mm, range, 0-21 vs 4.9 ± 2.6 mm, range, 0-15 mm, $P = .036$) compared with those with TAVs (Figure 6). The circumference and the area of the aortic root were larger in patients with TAV compared with BAV. The detailed data comparing patients with BAV and TAV are presented in Table 4.

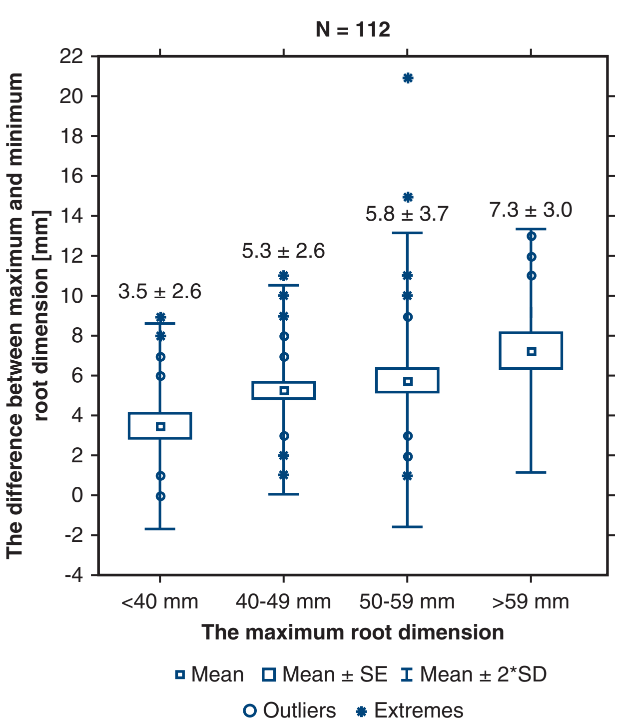


FIGURE 4. Difference in the measurements of the minimum and maximum aortic root dimension with respect to the maximum aortic root diameter (n = 112). *SD*, Standard deviation; *SE*, standard error.

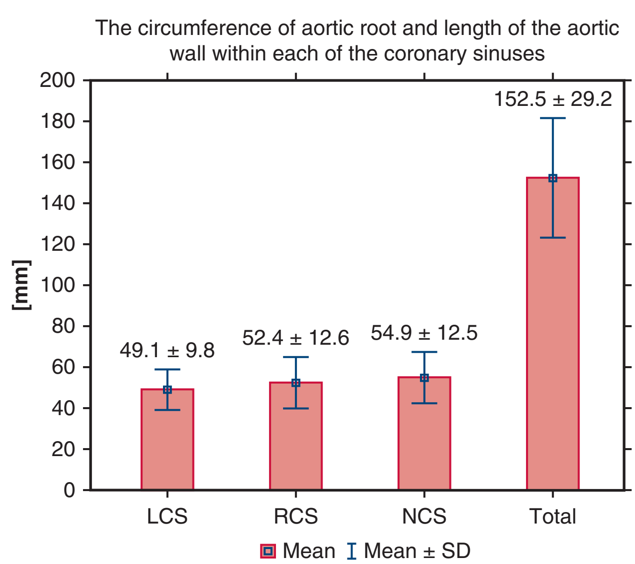


FIGURE 5. The circumference of the aortic root and the perimeter of the aortic wall within the sinus. *LCS*, Left coronary sinus; *NCS*, noncoronary sinus; *RCS*, right coronary sinus; *SD*, standard deviation.

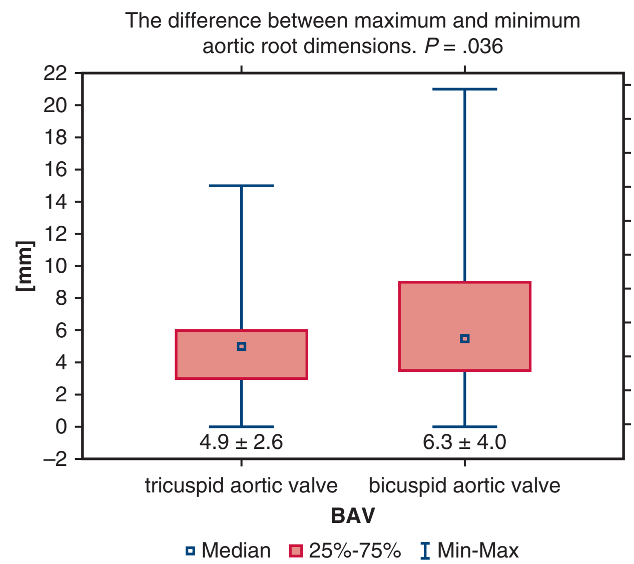


FIGURE 6. Difference in the measurements of the maximum and minimum aortic root dimensions in patients with BAVs and TAVs. *BAV*, Bicuspid aortic valve.

Standard 2-Dimensional Computed Tomography Angiography

The root dimensions measured without the 3D double oblique multiplanar reconstruction were as follows: for the axial plane 45.5 ± 9.0 mm (range, 23-72), for the coronal plane 46.1 ± 8.8 mm (range, 23-74), and for the sagittal plane 45.1 ± 8.9 mm (range, 23-71). The measurements performed in only 1 plane significantly underestimated the root dimension compared with the maximum root dimension measured using the 3D multiplanar reconstruction ($P = .0017$ for axial plane, $P = .0087$ for coronal plane, and $P = .0006$ for sagittal plane).

Echocardiography

The root dimension measured in TEE in the parasternal long-axis view was on average 44.8 ± 8.4 mm (range, 24-70 mm). It differed significantly (4.2 ± 2.8 mm; range, 0-14 mm) from the maximum root dimension measured in the double oblique 3D multiplanar reconstruction ($P < .001$).

Intra- and Interobserver and Variability

The interobserver variability for the maximum root dimension was 0.91 (95% CI, 0.89-0.93), and the intraobserver variability was 0.95 (95% CI, 0.93-0.97), and for the minimum root dimension was 0.90 (95% CI, 0.88-0.92) and 0.93 (95% CI, 0.91-0.94), respectively. The inter- and intraobserver variability for the root circumference was 0.88 (95% CI, 0.86-0.89) and 0.93 (95% CI, 0.90-0.96) and for the root area was 0.87 (95% CI, 0.85-0.89) and 0.90 (95% CI, 0.88-0.92), respectively.

DISCUSSION

Underestimation of aortic dimensions has been analyzed only in patients with abdominal aortic aneurysms.[10-13] So far, there have been no studies evaluating this phenomenon in the case of the aortic root. This is the first study that evaluates the difference in the measurements of the maximum and minimum aortic root dimensions and compares the maximum root dimensions with those obtained from echocardiography and 2D CT angiography. The findings of this study can be summarized as follows: (1) The "diameter" of the aortic root does not exist because it is asymmetric and not circular; (2) there is a statistically significant difference in the measurements of the minimum and maximum aortic root dimensions, especially in patients with BAVs; and (3) aortic root dimensions can be significantly underestimated by echocardiography or based on the measurements performed only in 1 plane (sagittal, coronal, axial).

The aortic root is asymmetric, and on the basis of the results of our study, the difference in the measurements of

TABLE 3. Measurements of the aortic root performed using 3-dimensional multiplanar reconstruction

	All patients (n = 112)	Female (n = 34)	Male (n = 78)	*P* value*
Minimum root dimension (mm)	43.7 ± 8.4 (range, 23-67)	39.1 ± 7.8	45.7 ± 8.0	<.001
Maximum root dimension (mm)	49.1 ± 9 (range, 24-74)	44.2 ± 9.4	51.2 ± 8.0	<.001
Cusp-commissure distance from the LCS (mm)	46.7 ± 8.7 (range, 24-64)	41.8 ± 7.6	49.0 ± 8.3	.001
Cusp-commissure distance from the RCS (mm)	45.8 ± 9.3 (range, 25-69)	41.7 ± 8.7	47.7 ± 9.1	.010
Cusp-commissure distance from the NCS (mm)	45.9 ± 9.1 (range, 23-69)	40.1 ± 7.3	48.7 ± 8.6	<.001
Sinotubular junction (mm)	42.8 ± 9 (range, 18-67)	38.8 ± 7.2	44.5 ± 9.2	.003
Ascending aorta (mm)	50.6 ± 10.5 (range, 21-79)	53.4 ± 9.7	49.4 ± 10.6	.067
Root area (cm^2)	17.3 ± 6.3 (range, 4.5-35.4)	14.4 ± 6.4	18.6 ± 5.8	<.001
Perimeter of the root (mm)	152.5 ± 29.2 (range, 81-236)	138.8 ± 32.4	158.4 ± 25.6	.001
Perimeter of the aortic wall within LCS (mm)	49.1 ± 9.8 (range, 21-81)	46.2 ± 10.8	9.1	.086
Perimeter of the aortic wall within RCS (mm)	52.4 ± 12.6 (range, 30-87)	47.7 ± 13.6	54.7 ± 11.5	.029
Perimeter of the aortic wall within NCS (mm)	54.9 ± 12.5 (range, 29-88)	48.8 ± 12	57.8 ± 11.8	.004

LCS, Left coronary sinus; *NCS*, noncoronary sinus; *RCS*, right coronary sinus. **P* value for comparison between male and female patients.

TABLE 4. Comparison of the aortic root measurements between patients with bicuspid and tricuspid aortic valves

	Tricuspid aortic valve (n = 72)	Bicuspid aortic valve (n = 40)	*P* value
Minimum root dimension (mm)	45 ± 8.8	41.3 ± 7.4	.024
Maximum root dimension (mm)	49.9 ± 9.5	47.5 ± 7.9	.175
Sinotubular junction (mm)	44.1 ± 9.9	40.3 ± 6.5	.044
Ascending aorta (mm)	50 ± 11.3	51.9 ± 8.6	.365
Root area (cm^2)	20 ± 12.4	15.8 ± 5.3	.045
Perimeter of the root (mm)	156.5 ± 30.9	145.3 ± 24.5	.051

its minimum and maximum dimensions is significant. The measurement of the aortic root dimensions based only on transthoracic long-axis echo assessment or performed in only 1 plane (sagittal, coronal, axial) in CT may be significantly underestimated. In our study, the difference in the measurements of the minimum and maximum dimensions exceeded 5 mm in half of the patients. It was even more evident in patients with BAVs in whom the difference exceeded 6 mm. In 1 patient, the difference was bigger than 20 mm.

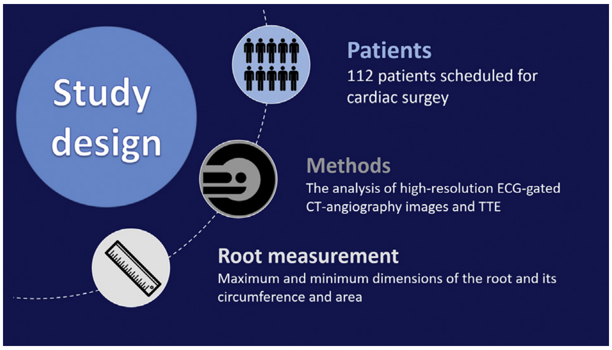
A correct estimation of the dimension of the aortic root is essential for a precise diagnosis and subsequent treatment plan.[14-18] However, the standard measurements obtained from the echocardiography in the long-axis and 2D CT angiography underestimated the maximum root dimension on average by more than 4 mm. Underestimation of the maximum aortic root dimension may result in an unnecessary delay in the implementation of an optimal medical therapy or a surgical intervention and put the patient at risk of developing life-threatening complications.[19,20] In our opinion, the optimal method to measure aortic root is the evaluation of the cross-section of the aorta using a 3D multiplanar reconstruction mode in high-resolution CT or MRI. This allows for a detailed assessment of the whole aorta and reduces the risk of improper estimation of aortic dimensions. Moreover, it should be emphasized that the ECG gating is necessary to assess the aortic root properly. The artifacts that are present in the non–ECG-gated examinations make it impossible to properly evaluate the dimensions of the aortic root.

The minimum-maximum difference of aortic root dimensions was bigger in patients with BAVs. The asymmetry of BAVs suggests that aortas in these patients should be evaluated more cautiously, preferably using CT angiography or MRI to additionally assess the whole aorta.

One of the ways to assess aortic root enlargement, proposed mainly for patients with connective tissue disorders, for example, Marfan syndrome and BAVs, is the aortic root area/patient's height ratio (AHr).[21,22] In 2002, Svensson and colleagues[21] proposed an assessment of the AHr to evaluate the risk of aortic complications when the multiplanar analysis of the aorta was not commonly accessible. The authors proposed measuring the area as a circle (πr^2) based on the maximum root diameter. In our study, the real cross-sectional area of the aortic root was significantly smaller compared with the one measured as a circle. In our opinion, the planimetric estimation of the root area is a more precise parameter to assess the real AHr.

The largest sinus in our patients was the noncoronary sinus, which reflects the normal anatomy of the aortic root in humans. The left coronary sinus was the smallest one and had the lowest variability among patients (the lowest standard deviation). This may be explained by the anatomic localization of this sinus. It is surrounded by the pericardial sac and the left ventricle, and has potentially less space to dilate than other sinuses.

Defining the true maximum dimension should be the gold standard when assessing a patient's aorta. The aortic dimension influences the stress in the aortic wall.[23] It is currently the most commonly used parameter to assess the risk of dissection and should be measured meticulously. The aortic root is asymmetric and cannot be properly measured in 1 random cross-section, especially in patients with BAV. However, the clinical guidelines still regard echocardiography in parasternal long-axis view as the optimal method for the measurement of this structure. This is a serious misconception that may result in the underdiagnosis of aortic root aneurysms and delay an initiation of proper treatment. Our study shows that the dimensions of the root measured using multiplanar 3D



VIDEO 1. The standardized method for measuring the aortic root. Video available at: https://www.jtcvs.org/article/S0022-5223(18)32044-0/fulltext.

reconstruction are significantly larger compared with those evaluated in echocardiography or 2D CT angiography. Therefore, we suggest that the standardized method presented in this article should be used to assess the aortic root and avoid underestimation of the maximum aortic root dimension, a potentially dangerous diagnostic mistake. Moreover, both the intra- and interobserver variability values indicated that this method was reproducible and accurate. We currently use the 3D reconstruction to assess the CT angiography of our patients, which makes it easier to properly assess the aorta and decide whether to operate on the patient or not. Nevertheless, a large prospective study is necessary to evaluate whether a more precise estimation of the aortic root dimensions influences the patient outcomes.

CONCLUSIONS

The aortic root is asymmetric and not circular. The difference in the measurements of the minimum and maximum aortic root dimensions is significant and may exceed 20 mm, especially in patients with BAVs whose aortic roots are more asymmetric. Aortic root dimensions can be significantly underestimated when using a measurement performed in only 1 plane (sagittal, coronal, axial) in 2D CT angiography or echocardiography (Video 1).

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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