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The role of trans-thoracic echocardiography in the assessment of aortic annular diameter

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Abstract

We aimed to compare two-dimension transthoracic echocardiogram (2D-TTE) and three-dimension transthoracic echocardiogram (3D-TTE) measurements of the aortic annular diameter using multi-detector CT (MDCT) as a gold standard.

This prospective observational study included 50 consecutive patients who came to the cardiology department, Al-Azhar University Hospital, New Damietta, for MDCT coronary angiography. The study was carried out in the period from July 2016 until February 2017. All patients were subjected to informed consent, clinical history, physical examination, transthoracic echocardiography 2D and 3D, and MDCT.

The aortic annular areas measured by MDCT and 3D-TTE were significantly larger than areas by 2D-TTE. A good correlation ($r=$ 0.82) was observed between the areas obtained by 3D-TTE and MDCT; however, the correlation between the values by 2D-TTE and MDCT was rough ($r=0.30$). Eccentricity Index (EI) values in 28% of the patients were greater than 0.1, that is, the aortic annulus was elliptical.

Accuracy of aortic annular diameter measurement by 3D-TTE was superior to that by 2D-TTE. Three-D TTE and MDCT revealed that the shape of the aortic annulus was elliptical in 28% to 30% respectively of study subjects. There is a strong concordance between the minimum and the maximum diameter determine by 3D-TTE and MDCT.

Abbreviations: 2D-TTE = two-dimension transthoracic echocardiogram, 3D-TTE = three-dimension transthoracic echocardiogram, CI = confidence interval, CT = computed tomography, DM = Diabetes Mellitus, ECG = electrocardiogram, EI = eccentricity index, MDCT = multi-detector computed tomography, SD = standard deviation.

Keywords: Two-dimension transthoracic echocardiogram, 3D echocardiography, aortic annuals, multi-detector computed tomography

1. Introduction

Two-dimension transthoracic echocardiogram (2D-TTE) is a widespread imaging technique used to screen an aortic annulus.[1,2] Also, it is the most common non-invasive diagnostic modality, expert opinions are needed for data interpretation because of the intra-cardiac complex anatomy and its relation-ship with the surrounding tissues.[3,4] However, this technique has some limitations as the variation of results and interpretations when used by different investigators based on their imaginary reconstructions of cardiac structures. Besides, it can be affected by the patient's position and condition and, Doppler angle errors.[5] These limitations can be overcome using real-time three-dimension transthoracic echocardiogram (3D-TTE), which provides a detailed evaluation of cardiac physiology and anatomy in real-time.[6]

Three-D TTE is an emerging non-invasive technique based on real-time volumetric scanning and useful in evaluating cardiac chamber volumes and the left ventricular wall's motion.[7,8] It does not need extensive reconstruction after dataset acquisition as with computed tomography (CT) and magnetic resonance imaging. There is an increase in the exact measurement of the aortic annular diameter when measured by 3D echocardiography in relation to 2D measures. Moreover, 3D echocardiography gives more detailed anatomy. Since 2002 and till now, further advances have been made in 3D computer software technology as a matrix-array system, leading to better screening and evaluation of valvular and Congenital Heart Disease (CHD) in pediatric and adult populations.[9] Several studies have shown that the aortic annular diameter is underestimated with 2D echocardiography compared with the 3D when evaluated in patients with severe aortic stenosis.[10]

Multi-detector computed tomography (MDCT) is one of the most exciting technological revolutions in cardiac imaging, used

as a non-invasive assessment of coronary artery diseases, with new clinical applications arising over the past years.[11] Nevertheless, there is no evidence on the role of MDCT in valvular diseases.[12] Therefore, echocardiography has retained its clinical practice status, despite its limitations in assessing valvular morphology. This study aimed to compare 2D-TTE and 3D-TTE measurements of the aortic annulus diameter using multi-detector CT as a gold standard.

2. Patients and methods

In this study, we followed the rules and guidelines of the Strengthening the Reporting of Observational Studies in Epidemiology statement of observational studies.

2.1. Study design

This prospective observational study included 50 consecutive patients who came to the cardiology department, Al-Azhar University Hospital, New Damietta, for MDCT coronary angiography, which was used to exclude the coronary artery diseases, coronary artery anomalies, fistulas, and aneurysms. The study was carried over a period from July 2016 until February 2017. Informed consent was obtained from all patients, and ethical approval was obtained from the council of Al-Azhar University Hospital.

2.2. Selection criteria
2.2.1. Inclusion criteria. We included all patients with normal cardiac anatomy and function assessed by physical examination and standard 2D echocardiography.

2.2.2. Exclusion criteria. Patients with structural heart disease diagnosed by 2D-TTE, which is defined as an abnormality of the heart that affects the blood flow. Many structural heart conditions are congenital, but these abnormalities can also form later in life after infection or result from other underlying conditions. These secondary causes, even in the mild form, can affect the actual measure of aortic annular diameter.

2.3. Techniques method
2.3.1. TTE. Patients underwent 2D-TTE and 3D-TTE at Echo-Lab in the cardiology department, Al-Azhar University Hospital, New Damietta, using a Philips IE-33 echocardiography machine. The probe used was the X5-1 phased array sector probe (frequency range 1.5–4.3 MHz). We used a hard disk for storage of imaging data before transformation into a personal computer for analysis. We recorded all imaging data of the long axis of a left ventricle (LV) and 3D zooming image of the aortic annulus in parasternal views in the full-volume for 4 consecutive beats.

2.3.2. Measurement of aortic annulus diameters by 2D and 3D echocardiography. The annulus diameters (r) were measured by 2D-TTE using the zoomed images at the insertion of the leaflets in the mid-systolic phase from the parasternal long-axis view. We used this equation [area = π (r/2)^2] to calculate the annular area by presuming the annulus' shape to be circular. We used the cutting image of 3D-TTE to evaluate the maximum and minimum diameters of the aortic annulus, where the shape of the aortic annulus was mostly circular, obtained by a piece of analysis software (Q-Lab 10). Besides, the aortic annulus was traced, and the area was measured in the same image (Fig. 1).

2.3.3. Multi-detector CT (MDCT). Electrocardiogram (ECG)-gated MDCT images were acquired using a 160-slice Dual-Source CT scanner (Toshiba) machine. Contrast enhancement was achieved with ULTRAVIST (iopromide) injected into the antecubital vein (20–50 ml) followed by a 30-ml saline bolus. We obtained 3 cross-sectional views (axial view, sagittal view, and coronal view) after image reconstruction at the timing of 200 ms from the R wave of the ECG. Then, the maximum and minimum diameters and the aortic annular areas were measured using the cutting images involving the aortic annulus obtained along the short axis (Fig. 2).

2.4. Statistical analysis

We used the "Data Collection Form" to collect and tabulate the collecting data before its transformation into a computerized database. Continuous variables were presented as mean±SD, while qualitative variables were expressed as numbers and percentages. Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS Software, version 22). In 50 randomly selected studies, aortic annulus diameters were remeasured by the same observers at 3 separate times to determine intraobserver concordance and by another 2 observers to determine interobserver agreement. Intra- and inter-observer concordance were evaluated for 2D and 3D echocardiography and CT. Correlations were done to test for linear relations between variables. Measurements determined by MDCT were compared with those obtained by 3D-TTE and 2D-TTE using Bland-Altman analysis. P value was considered significant if <.05.

3. Results

3.1. Demographic data

This study included 50 patients with a mean age of 37.5±10.65 years. Out of them, 34 (68%) were males. Regarding the clinical presentation, 13 patients (26%) were hypertensive, and 10 (20%) were diabetics, systolic BP of the study population ranged between 90 and 160 mm Hg, their diastolic BP ranged between 60 and 100 mm Hg. Table 1 presents all demographic and clinical data for the enrolled population.

3.2. Comparison between MDCT and 2D findings

There were statistically significant differences between mean 2D systolic aortic annular diameter and mean minimum (P=.002), and maximum aortic annular diameter derived from MDCT (P<.001). Also, there was a statistically significant difference between the mean aortic annular area derived from 2D and MDCT (P<.001). Table 2 shows the finding of 2D-TTE.

There was a weak positive correlation between 2D-TTE systolic aortic annular diameter and minimum (P=.002, r=0.42) and maximum aortic annular diameter derived from MDCT (P=.006, r=0.38). Also, the mean 2D-TTE aortic annular area presented a weak positive correlation with the mean aortic annular area derived from MDCT (P=.031, r=0.31).

3.3. Comparison between MDCT and 3D findings

There was no statistically significant difference between mean 3D-TTE minimum aortic annular diameter and mean minimum aortic annular diameter derived from MDCT (P=.37). In terms
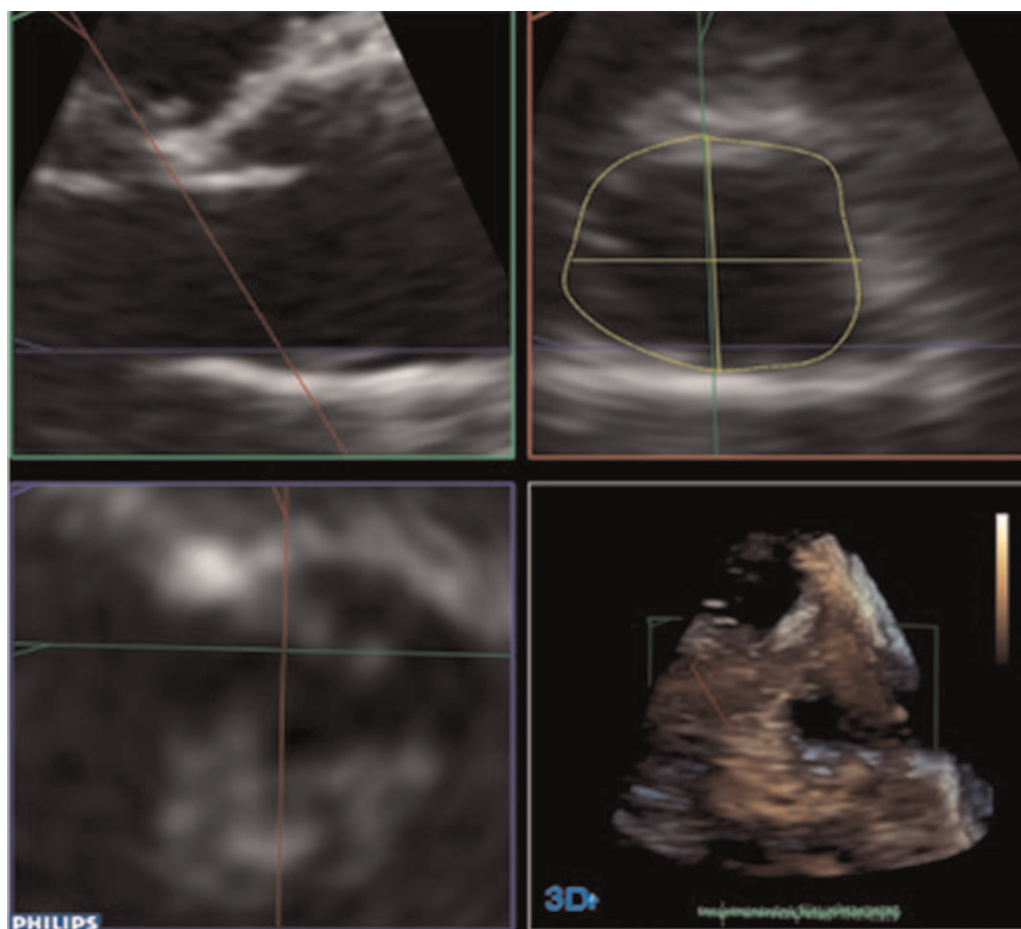
Figure 1. 3D-TTE multi-planar reformations of the aortic root.

of mean maximum aortic annular diameter, there was no statistically significant difference between mean 3D-TTE and MDCT (P = .31). Also, there was no statistically significant difference between the mean 3D-TTE eccentricity index (EI) and the mean EI derived from MDCT (P = .16). On the other hand, there was a statistically significant difference between the mean 3D-TTE derived aortic annular area and the mean aortic annular area derived from MDCT (P = .001). Table 2 shows the main finding of 3D-TTE and MDCT.

There was an excellent positive correlation between 3D-TTE minimum aortic annular diameter and minimum aortic annular diameter derived from MDCT (P < .001, r = 0.81). Also, between 3D-TTE maximum aortic annular diameter and maximum aortic annular diameter derived from MDCT (P < 0.001, r = 0.8). Nevertheless, there was a weak positive correlation between 3D-TTE EI and EI derived from MDCT (P < .02, r = 0.43). Regarding the mean aortic annular area, there was an excellent positive correlation between 3D-TTE and MDCT (P < .001, r = 0.82). The concordance between minimum aortic annular diameter determined by 3D-TTE and MDCT (average bias 0.06 cm, 95% CI −0.32 to 0.44 cm) was high and showed a small difference (Fig. 3A). Also, there is a small difference between the maximum aortic annular diameter determined by 3D-TTE and MDCT (average bias 0.075 cm, 95% CI −0.36 to 0.516 cm) (Fig. 3B). The concordance between the annular area determined by 3D-TTE and MDCT (average bias 0.29 cm, 95% CI −0.24 to 0.83

cm) was better than the concordance between the annular area determined by 2D-TTE and MDCT (average bias 0.76 cm, 95% CI −0.39 to 1.92 cm) (Fig. 3 C and D).

3.4. Comparison between 2D-TTE and 3D-TTE findings

There was a statistically significant difference when compared 2D-TTE systolic aortic annular diameter against mean minimum (P = .017) and mean maximum aortic annular diameter derived from 3D-TTE (P < .001). Also, there was a statistically significant difference between the mean aortic annular area derived from 2D-TTE and 3D-TTE (P < .001).

There was a weak positive correlation between 2D-TTE systolic aortic annular diameter and minimum (P = .003, r = 0.41) and maximum aortic annular diameter derived from 3D-TTE (P = .03, r = 0.36). On the other hand, there was no correlation between 2D-TTE aortic annular area and aortic annular area derived from 3D-TTE (P = .09, r = .24).

3.5. Correlation between demographic variables and aortic annular area

There are no correlations between [age, gender, diabetes mellitus (DM), or hypertension] and (annular area by MDCT, 3D-TTE, or 2D-TTE). Table 3 shows the relation between these variables.
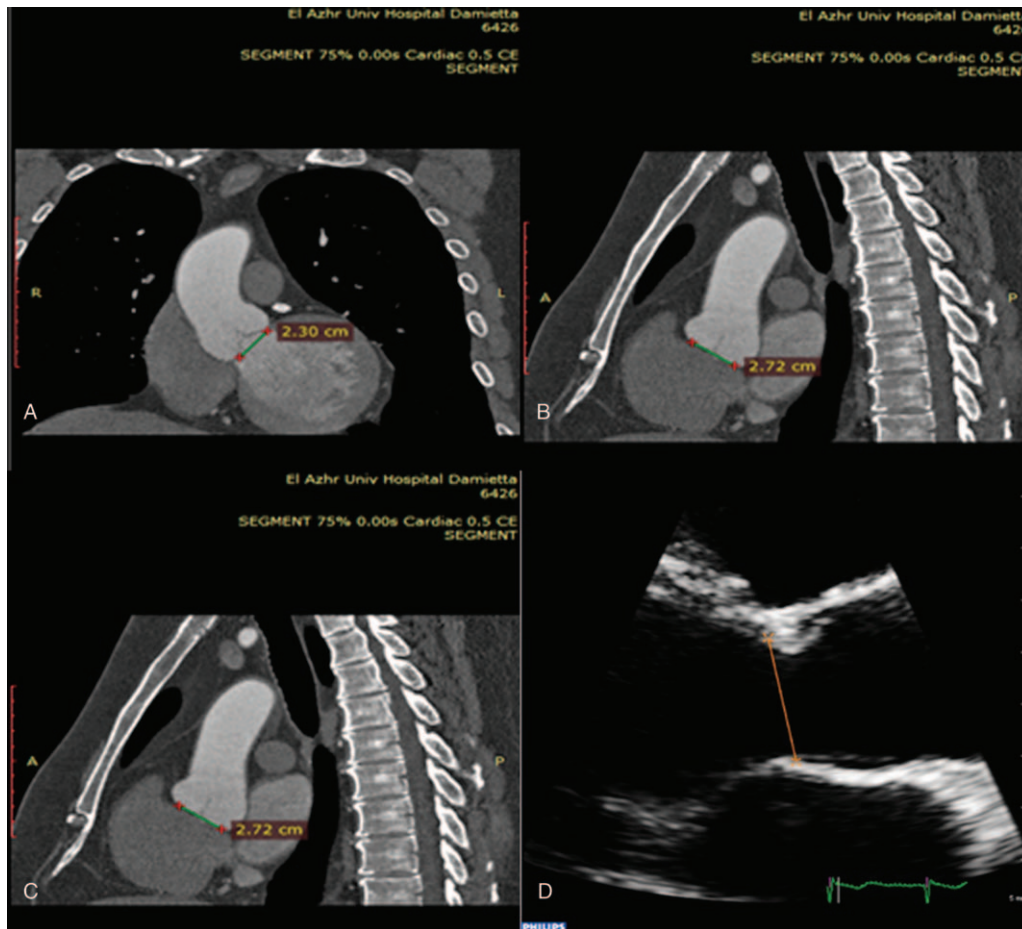
Figure 2. (A) Analysis of the aortic annulus by MDCT sagittal view; (B) Analysis of the aortic annulus by MDCT coronal view; (C) Analysis of the aortic annulus by MDCT axial view. (D) 2-DTTE zoomed images at the insertion of the leaflets from the parasternal long-axis view.

3.6. Observer agreement

Intraobserver correlation of measurements of the aortic annulus diameter performed on 2D-systolic, 2D-annular, 3D-minimum vertical, 3D-maximum diameter, 3D-annular area, CT minimum diameter, and CT maximum diameter was high. In addition, the interobserver correlation of measurements performed the same techniques was high (Table 4).

4. Discussion

Two-D TTE was widely used to screen patients and diagnose the aortic valve and other cardiac diseases.[13] Due to the difference between the sizes of aortic valve 3 leaflets, the use of 2D-TTE imaging in assessing aortic annulus based on the distance between 2 valvular hinge points on a 2D-TTE image will give an inaccurate measurement.[14] Therefore, many investigators tend to use 3D-TTE imaging techniques, which give more accurate measurements during the examination.[15] Thus, the present study was designed to compare 2D-TTE and 3D-TTE measurements of the aortic annular diameter using MDCT as a gold standard. It included 50 patients with normal cardiac anatomy and function assessed by physical examination and standard 2D-TTE. Patients with structural heart disease with 2D-TTE were excluded.

In the present study, the age of enrolled cases ranged between 18 years and 60 years, with a mean age of 37.5 ± 10.65. Out of the all patients, 34 (68%) were males, while 16 (32%) were females, 13 (26%) were hypertensive, 10 (20%) were diabetics, their body surface area ranged between 1.23 m^2 and 2.1 m^2 with

Table 1

Characteristics of the included patients in the study.

Characteristic	Value
Age, years	37.50 ± 10.65
Gender	
Male	34 (68%)
Female	16 (32%)
DM	
DM	10 (20%)
Not DM	40 (80%)
HTN	
HTN	13 (26%)
Not HTN	37 (74%)
SBP	123.30 ± 15.99
DBP	78.60 ± 9.95
BAS	1.59 ± 0.22

Values are mean ± SD or number (%).
BSA = body surface area, DBP = diastolic blood pressure, DM = diabetes mellitus, HTN = hypertension, SBP = systolic blood pressure.

Table 2

Measurements of aortic annular diameter using different echocardiographic modalities.

	Aortic annulus at minimum diameter	Aortic annulus at maximum diameter	Annular area	Eccentricity index
CT	2.52 ± 0.30^a	2.71 ± 0.37^a	5.08 ± 0.44^a	0.13 ± 0.22^a
2D-TTE	2.36 ± 0.15^b	-	4.32 ± 0.56^b	-
3D	2.46 ± 0.26^a	2.64 ± 0.28^a	4.79 ± 0.47^c	0.07 ± 0.06^a

2D-TTE = two-dimensional transthoracic echocardiography, 3D-TTE = three-dimensional transthoracic echocardiography, MDCT = multi detector computed tomography.
Data are means ± SD. Means within the same column carrying different superscripts are significantly different at ($P < .05$).
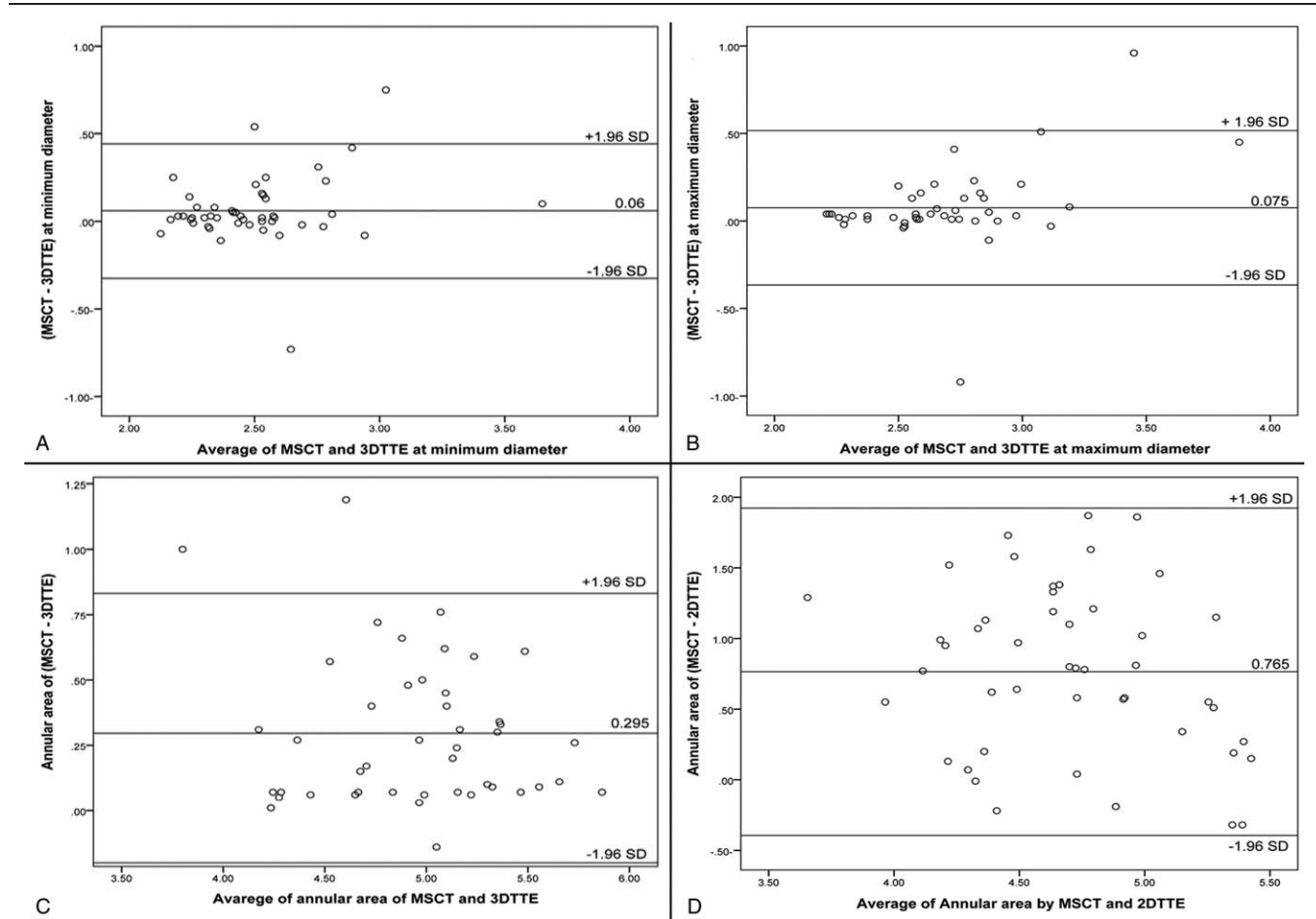
Figure 3. (A) Bland-Altman plots demonstrating the concordance of aortic annulus diameters determined by 3D-TTE to minimal diameters and minimal diameter by MDCT; (B) Bland-Altman plots demonstrating the concordance of aortic annulus diameters determined by 3D-TTE to maximal diameters and maximal diameter by MDCT; (C) Bland-Altman plots demonstrating the concordance of the annular area determined by 3D-TTE to the aortic area by MDCT; (D) Bland-Altman plots demonstrating the concordance of the annular area determined by 2D-TTE to the aortic area by MDCT.

Table 3

correlation between aortic annular diameters measured by different techniques and different parameters.

Parameters	CT annular area		3D annular area		2D annular area	
	r	*P* value	*r*	*P* value	*r*	*P* value
Age	0.17	.23	0.14	.30	0.13	.33
Sex	0.03	.82	0.15	.27	0.08	.57
DM	0.04	.77	0.07	.60	0.14	.33
HTN	0.12	.39	0.09	.52	0.17	.23
SBP	0.13	.34	0.19	.18	0.09	.53
DBP	0.04	.77	0.05	.70	0.14	.33
BSA	0.11	.44	0.03	.79	0.29	.04

2D-TTE = two-dimensional transthoracic echocardiography, 3D-TTE = three-dimensional transthoracic echocardiography, MDCT = multi detector computed tomography.

Table 4

Intraobserver and interobserver correlation coefficient (*r*) and Confidence interval of measurements of the aortic annulus diameter by different imaging modalities.

	Interobserver correlation		Intraobserver correlation	
	Correlation	**95% CI**	**Correlation**	**95% CI**
2D systolic	$r=0.71$	0.58 to 0.80	$r=0.92$	0.87 to 0.95
2D annular	$r=0.63$	0.47 to 0.77	$r=0.95$	0.92 to 0.97
3D minimum vertical	$r=0.92$	0.88 to 0.95	$r=0.97$	0.95 to 0.98
3D maximum diameter	$r=0.88$	0.82 to 0.92	$r=0.96$	0.93 to 0.97
3D annular area	$r=0.87$	0.80 to 0.92	$r=0.94$	0.90 to 0.96
CT minimum diameter	$r=0.90$	0.85 to 0.94	$r=0.96$	0.95 to 0.98
CT maximum diameter	$r=0.85$	0.78 to 0.91	$r=0.94$	0.91 to 0.96

2D = 2-dimensional, 3D = 3-dimensional, CI = confidence interval, CT = computed tomography.

(mean $\pm$ SD $= 1.59 \pm 0.22\,m^2$). According to our analysis, there are no correlations between these variables and aortic annular diameter.

In terms of systolic diameter in 2D-TTE, the mean diameter was 2.36 ± 0.15 cm. Those findings are somewhat similar to several recent studies such as Chikage et al where the mean diameter was 2.13 ± 0.23 cm.[16] This discrepancy in results may be attributed to the previous study does not exclude patients with structural heart disease as 9% of their study population had valvular heart disease and 5% was diagnosed as cardiomyopathy. There was a statistically significant difference between 2D-TTE and MDCT ($P = .002$) and rough correlation ($r = .422$). In the present study, the mean annular area by 2D-TTE was $4.33 \pm 0.55\,cm^2$, with a significant difference compared with MDCT ($P < .001$). This finding was somewhat similar to Yoon et al,[17] where the mean was $4.30 \pm 0.76\,cm^2$. The mean annular area by MDCT was $5.11 \pm 0.46\,cm^2$. This finding was somewhat similar to Gurvitch et al,[18] where the mean was $5.16 \pm 0.32\,cm^2$. In contradiction with the results of Arnold et al, where the mean was $4.57 \pm 0.74\,cm^2$.[19] This finding was somewhat similar to Chikage et al where they reported a significant difference between mean aortic annular area derived by 2D-TTE 3.60 ± 0.8 and MDCT $4.16 \pm 0.7\,cm^2$ with a significant difference ($P > .001$).[16] In the term of 3D-TTE, the mean maximum diameter was 2.64 ± 0.28 cm, while in the study of Chikage et al, the mean was 2.35 ± 0.3 cm.[16] There was no significant difference between the mean maximum diameter in 3D-TTE and MDCT ($P = .31$). These results are somewhat similar to many recent studies such as Schultz et al, where the mean was 2.69 ± 0.28 cm,[6] while the results of the study of Khalique et al was 2.56 ± 0.26 cm.[20]

The aortic annular areas measured by MDCT and 3D-TTE were significantly larger than 2D-TTE (5.11 ± 0.46, 4.79 ± 0.47, and $4.33 \pm 0.55\,cm^2$, respectively). A good correlation ($r = 0.82$) was observed between the values obtained by 3D-TTE and MDCT; however, the correlation between the values by 2D-TTE and MDCT was weak ($r = 0.30$). Altiok et al reported a high correlation between 3D-TTE and MDCT concerning sagittal diameter r ($r = 0.77$) and coronal diameter ($r = 0.88$).[11]

In the present study, the EI by the 3D-TTE echo ranged between 0.01 and 0.21, with a mean of 0.07 ± 0.06 cm. Moreover, 14 of the 50 patients had EI $\geq$ 0.1, that is, the aortic annulus was elliptical in 28% of the patients. In contradiction with the results of Chikage et al, where mean EI was 0.11 ± 0.08 cm, and 70 of the 153 patients had EI$\geq$ 0.1, that is, the aortic annulus was elliptical in 46% of the patients.[16] This discrepancy in finding may be attributed to different inclusion criteria. Also, the EI by MDCT ranged between 0.01 and 0.93 with a mean of

0.11 ± 0.2 cm. Fifteen of the 50 patients had EI $\geq$ 0.1, that is, the aortic annulus was elliptical in 30% of the patients.

In the comparison between 2D-TTE and 3D-TTE, our findings demonstrated a weak positive correlation between 2D-TTE systolic aortic annular diameter and minimum ($P = .003$, $r = 0.41$) and maximum aortic annular diameter derived from 3D-TTE ($P = .03$, $r = .36$). In contradiction with the results of Martin et al,[21] where the correlation was good between the 2D-TTE and 3D-TTE minimum diameter ($r = 0.81$, $P < .0001$) and maximum diameter ($r = 0.80$, $P < .0001$). Besides, we reported a statistically significant difference when compared 2D-TTE systolic aortic annular diameter against mean minimum ($P = .017$) and mean maximum aortic annular diameter derived from 3D-TTE ($P < .001$). But Martin et al, reported insignificant difference ($P = .44$). This variation and difference may be due to the demographical variation they enrolled children with mean age 11 ± 3.6 years.[21] Moreover, there was a statistically significant difference between the mean aortic annular area derived from 2D-TTE and 3D-TTE ($P < .001$). These findings are supported by Chikage et al, as they reported a significant difference in both techniques ($P > .001$).

Our findings regarding the minimum diameter in MDCT (2.51 ± 0.13 cm) were somewhat similar to several recent studies such as Arnold et al, where the mean minimum diameter was 25.5 ± 2.1 cm.[19] On the other hand, these findings were in contradiction with the findings of the study by Schultz et al, the mean minimum diameter was 2.17 ± 0.21 cm, and this discrepancy in findings may be attributed to the that their study mainly done on patients with severe aortic stenosis and 37% of them had impaired LV systolic function.[6] Also, in contradiction with Khalique et al, the mean minimum diameter of their patients was 2.14 ± 0.28 cm due to the different inclusion criteria as their study included 100 patients with severe and symptomatic aortic stenosis who underwent trans-cutaneous aortic valve implantation (TAVI).[20]

This study highlighted the accuracy of measuring aortic annular diameter by 3D-TEE compared to the 2D-TTE and MDCT. This finding is very important, especially for cardiothoracic surgeons. The preoperative measurement of aortic annular size by 3D-TEE provides them accurate annular information and helps them make a detailed surgical plan before surgery, particularly predicting aortic annular enlargement during the operation. Besides, the accuracy of the 3D-TEE measurement we showed in this study indicates that 3D-TEE could be a feasible alternative to contrast CT for Transcatheter aortic valve implantation (TAVI) patients if contrast CT is not available or contraindicated for some reasons.

We performed an image reconstruction by MDCT at the timing of 200 ms from the R wave of the ECG. On the other hand, we measured the aortic annular diameter by 3D-TTE in the mid-systolic phase when the aortic valve was open at maximum. Also, image qualities by 3D-TTE were inferior to those by a 3D-transesophageal echocardiogram (TEE). Another limitation is the small sample size of the included patients; however, this may be due to our restricted criteria.

5. Conclusion

We conclude that aortic annular areas measured by 3D-TTE had good concordance and correlation with MDCT. The accuracy of aortic annular diameter measurement by 3D-TTE was superior to that by 2D-TTE because the values by 2D-TTE were underestimated compared to those measured by 3D-TTE and MDCT. Three-D TTE and MDCT revealed that the shape of the aortic annulus was elliptical in 28% to 30% respectively of study subjects.

Author contributions

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