COMPARISON OF PREOPERATIVE NONINVASIVE AND INTRAOPERATIVE MEASUREMENTS OF AORTIC ANNULUS

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ABSTRACT

BACKGROUND

Precise preoperative assessment of aortic annulus diameter is essential for sizing of aortic valve especially in patients planned for transcatheter aortic valve replacement. Computed Tomographic (CT) and echocardiographic measurements of the aortic annulus vary because of elliptical shape of aortic annulus. This study was undertaken to compare the measurement of aortic annulus intraoperatively with preoperative noninvasive methods in patients undergoing aortic valve replacement.

MATERIALS AND METHODS

Aortic annulus diameter was measured with cardiac CT and Transesophageal Echocardiography (TEE) prior to open aortic valve replacement in 30 patients with aortic valve stenosis. In CT, aortic annulus dimensions were measured in coronal plane, sagittal oblique plane and by planimetry. Both 2-dimensional and 3-dimensional TEE were used. These were compared with intraoperative measurements done by valve sizers and Hegar dilators. Pearson analysis was applied to test for degree of correlation.

RESULTS

CT in coronal and sagittal oblique plane tends to overestimate the diameter of aortic annulus when compared with intraoperative measurements (coefficient of relation, $r = 0.798$ and 0.749, respectively). CT measurements in single oblique plane showed a weaker correlation with intraoperative measurements than 3D TEE and 2D TEE ($r = 0.917$ and 0.898, respectively). However, CT measurements by planimetry method were most correlating with the intraoperative measurements ($r = 0.951$).

CONCLUSION

Noninvasive investigations with 3-dimensional views (CT-based measurement employing calculated average diameter assessment by planimetry and 3-dimensional TEE) showed better correlation with intraoperative measurement of aortic annulus. CT-based aortic annulus measurement by planimetry seems to provide adequate dimensions most similar to operative measurements.

KEYWORDS

Aortic Annulus, Computed Tomography, 3-Dimensional Echocardiography, Intraoperative, Planimetry, Valve Sizers.

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INTRODUCTION: Transcatheter Aortic Valve Implantation (TAVI) has proved to be an efficient alternative to the conventional surgical Aortic Valve Replacement (AVR) in high risk patients with severe symptomatic Aortic Stenosis (AS).[1,2,3] An exact measurement of the aortic annulus is critical for appropriate patient selection and successful implantation. Paravalvular aortic regurgitation can be observed in at least 50% of patients being one of the most common limitations.[4] To minimise paravalvular aortic regurgitation, exact annular measurements and prosthesis sizing are critical. This accurate measurement is required only for patients undergoing TAVI as in open valve replacement root enlargement procedure can be added with no change in morbidity or mortality. Different noninvasive methods of preoperative annulus measurements have been used over time: Transthoracic Echocardiography (TTE), Transesophageal Echocardiography (TEE), calibrated aortic angiography and recently Multislice Computed Tomography (MSCT).[5] Invasive methods of annulus measurement like balloon aortic valvuloplasty using a manometric balloon have been used with good results.[6] In TEE, the diameter of the aortic annulus including all cusp calcifications is measured on the midesophageal long axis view of the ascending aorta and aortic valve at end-systole according to guidelines from the American Society of Echocardiography. Although, MSCT is able to provide detailed information about the shape of the aortic annulus and its surrounding structures. The use of this method in reoperative annulus sizing in TAVR patients is not standardised and is therefore not routine. Both TEE and MSCT may yield different results depending on the view due to the elliptic shape of the aortic annulus, which should be regarded as a serious limitation. With the recent introduction of 3-dimensional (3D) study techniques in both echocardiography and computed tomography, the understanding and evaluation of anatomy of various structures has improved. The purpose of this study was to compare the intraoperative measurement of the aortic annulus during surgery in patients undergoing conventional aortic valve replacement with noninvasive methods by means of TTE, 2 and 3 dimensional TEE and MSCT.

AIMS AND OBJECTIVES: To compare the measurement of the aortic annulus measured with noninvasive methods:

- 2D transthoracic echocardiography.
- 2D transesophageal echocardiography.
- 3D transesophageal echocardiography and
- Multislice computed tomography.
- Single oblique plane - Coronal and Sagittal.
- Planimetry method - Calculated Average Annulus Diameter (CAAD) with intraoperative measurement of aortic annulus in patients undergoing AVR for severe AS.

MATERIAL AND METHODS: This study was a prospective nonrandomised study in a tertiary care centre.

Study Sample: The study population consisted of 30 patients (mean age 51±14.4 years, 22 men) diagnosed and operated for aortic valvular stenosis between July 2011 and November 2012. All patients underwent conventional aortic valve replacement for severe aortic valve stenosis and preoperative Electrocardiographic (ECG) gated dual source Computed Tomography (CT) of the chest and TEE as part of their preoperative assessment. Patients with associated moderate-to-severe AR were excluded from the study. Operative measurements were performed with valve sizers and Hegar dilators after decalcification.

Computed Tomographic Protocol: All CT examinations were performed on 64 multislice detector scanner (Toshiba Aquilion) with processing on dedicated workstation equipped with Aquarius iNtuition (TeraRecon Inc., San Mateo, CA). The CT angiography data acquisition was done with area coverage from carina to domes of diaphragm with a bolus of non-ionic iodinated contrast material about 90 mL injected through an 18-gauge needle in right antecubital vein with a flow rate of 4.5 mL/second followed by saline bolus of 40 mL by a pressure injector. The data acquisition was done with retrospective ECG gating technique with tracker in the descending thoracic aorta and preset Hounsfield units of 120 with following parameters: tube current 200mA, voltage 120 kV, collimation (slice thickness) = 0.5 mm, gantry rotation time 0.33 sec and scan direction craniocaudal. Additional beta blockers were not administered for regulation of heart rate.

Two predefined approaches were undertaken for assessment of aortic annulus diameters including leaflet calcification. First, the annular diameters were calculated in both coronal and sagittal oblique plane. The sagittal oblique plane has the similar orientation as parasternal long axis view on TTE and mid oesophageal long axis view on TEE. By reviewing the reconstructed double oblique transverse view at the level of the aortic valve, the correct position of the intersection of both views in the centre of the aortic valve defined as the conjuncture of the three cusps was ensured (Figure 2). Using coronal and sagittal oblique views, the diameter of aortic annulus was determined as the distance between the depicted hinge points of the aortic valve cusp ("hinge to hinge").

Second, the dimensions of the aortic annulus were further assessed employing the concept of a virtual ring joining the basal attachments of all three aortic valve cusps representing the inlet from the left ventricular outflow tract into the aortic root. Using the coronal and sagittal oblique views, the corresponding double oblique transverse view was adjusted to transect through the basal attachments of all three cusps. In order to assess the cross-sectional area, the luminal contours were tracked on the double oblique transverse plane using automatic vessel analysis with manual correction. The cross-sectional area was calculated and the maximal and minimal diameters as displayed by the segmentation software were noted. Using the equation for the area of a disk ($\pi \times r^2$), the average diameter of the encircled area was calculated (Calculated Average Annulus Diameter [CAAD]). All the measurements were taken at end systole and analysed on the workstation for measurement of aortic annulus by a single radiologist.

Echocardiographic Protocol:

2D Transthoracic Echocardiography: Echocardiographic studies were performed with a commercially available echocardiographic system Philips iE33 echocardiography system. Dimensions of the aortic annulus were assessed on the parasternal long axis view of the ascending aorta and aortic valve at end-systole according to the American Society of Echocardiography guidelines.[7,8] The aortic annulus diameter defined as the distance between the depicted hinge points of the aortic valve leaflets was assessed using the inner edge-to-inner edge technique including leaflet calcification.

2D and 3D Transesophageal Echocardiography: TEE was performed with a commercially available echocardiographic system (iE33; Philips Medical Systems) and a TEE probe (xMATRIX) allowing acquisition of 2D and 3D TEE images in midesophageal long axis views.[9,10]

Intraoperative Measurements: Aortic annulus size was assessed intraoperatively after resection of the aortic valve cusps and after decalcification of the aortic annulus and root in patients with aortic valve calcification and stenosis. Aortic valve sizers were inserted in the aortic annulus. Complete elastic fit of the biggest sizer was defined as optimal.

STATISTICAL ANALYSIS: Descriptive statistics was used. Data were expressed as mean±S.D. or mean (range) as appropriate. All statistical calculations were performed using the statistical package for social sciences (SPSS) II software for windows version 17.0. All continuous variables were evaluated by Kolmogorov-Smirnov test for normal distribution and were reported as mean±2 standard deviation. Pearson correlation analysis and Bland-Altman plots for regression analysis with assessment of systematic bias and 95% confidence intervals (limits of agreement calculated as mean difference ± 1.96 standard deviation of the difference) were used to assess agreement for anatomic measurements by the different measurement techniques. We performed an analysis of variance for repeated measurements and the F test. The Student's t-test for multiple comparisons was used for post hoc comparisons. A p value less than 0.05 was considered statistically significant.

RESULTS: All 30 patients underwent preoperative assessment of diameter of aortic valve and size measured by each method was compared with intraoperatively measured diameter. 3 out of 30 patients had bicuspid aortic valve. The mean ejection fraction of patients was 51.7±8.6% (20%-65%).

The mean diameter of aortic annulus assessed by TTE was 21.3±2.606 mm (16-27 mm). Mean diameter of aortic annulus as measured by 3-dimensional TEE and 2-dimensional TEE was 20.08±2.239 mm (16.5-27.4 mm) and 20.07±1.971 mm (17-25 mm), respectively. All continuous variables showed normal distribution as evaluated by Kolmogorov-Smirnov tests. Summary of patient-based results for different annulus measurement were grouped by size of surgically implanted valve prosthesis and are listed in Table 1.

Implanted valve size	N	Sagittal (mm)		Coronal		TTE		2-D TEE		3-D TEE		Intraoperative		p
		MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	
16	1	17.2	.	18.5	.	18	.	17.2	.	17	.	16	.	-
17	3	18.633	1.19	20.6	2.61	18.33	1.52	17.5	1.05	17.43	0.9	17.67	1.15	0.062
18	5	20.68	1.77	22.52	1.89	19.8	2.28	18.26	0.96	18.76	1.82	18.4	0.89	0.001
19	2	20.2	1.41	23.3	1.27	21	2.82	19.1	0.98	19.4	0	19	0	0.365
20	4	23.12	0.69	23.92	0.79	19.5	1	19.6	0.63	19.63	0.53	20	0	0.001
21	9	22.03	1.2	24.48	0.72	21.22	1.78	20.7	0.88	20.86	0.73	21	0	0.001
22	4	23.9	0.58	25.82	0.86	24	0	22.025	0.93	21.45	1.37	22	0	0.001
23	2	25.05	0.63	28.15	2.33	26	1.41	25.2	3.11	24.1	0.84	24.1	0.84	0.125
Total	**30**	**21.78**	**2.2**	**23.84**	**2.41**	**21.03**	**2.6**	**20.08**	**2.23**	**20.07**	**1.97**	**20.07**	**1.97**	

Table 1: Summary of Intraoperative and Preoperative Measurements of Aortic Annulus Grouped by Size of Surgically Implanted Aortic Valve Prosthesis (Implanted Valve Size) Expressed as Mean±Standard Deviation

Each of the analysis of Figure 1 indicates that CT tends to overestimate the diameter of aortic annulus when compared with intraoperative measurements (coefficient of relation, r = 0.798 - coronal view and 0.749 - sagittal view by average CT diameter) when assessed in single oblique plane. CT measurements in single oblique plane showed a weaker correlation with intraoperative measurements than 3D TEE and 2D TEE (r = 0.917 and 0.898, respectively). However, CT measurements by planimetry method were most correlating with the intraoperative measurements (r = 0.951). Most of the observations made by CT scan in single oblique plane were below the line of equity in the graphs whereas those by planimetry method were more nearer to the line of equity.

Based on the correlation study, the investigations in (Table 2) increasing order of correlation coefficient (r) for aortic annulus measurement were:

CT sagittal oblique plane < CT coronal oblique plane <TTE<2D TEE<3D TEE<CAAD.

All the noninvasive investigations were significantly correlating (p <0.001) with the intraoperative measurements.

Investigation	Spearman's coefficient of correlation (r)	Significance level (p)	95% Confidence Interval for rho
TTE	0.801	<0.0001	0.471 to 0.903
3-D TEE	0.917	<0.0001	0.831 to 0.960
2-D TEE	0.898	<0.0001	0.757 to 0.941

CT (CORONAL)	0.798	<0.0001	0.698 to 0.934
CT (SAGITTAL)	0.749	<0.0001	0.533 to 0.874
CAAD	0.951	<0.0001	0.898 to 0.976

Table 2: Table showing Comparison of Coefficient of Correlation(r) between Various Noninvasive Methods of Annulus Measurement and Intraoperative Measurement

Regression analysis between difference between intraoperative and noninvasive measurements (y-axis) and intraoperative measurements (x-axis).

Bland-Altman regression analysis was used for regression analysis. Each test was analysed taking intraoperative measurement as 'gold standard'. X-axis represents the 'gold standard' test against, which difference of the preoperative method with intraoperative method was plotted.

Horizontal lines represent the mean difference (labelled as mean) and the limits of agreement (labelled as ± 1.96 SD), which are defined as the mean difference plus and minus 1.96 times the standard deviation of the differences. According to Krouwer modification of Bland-Altman study, if the differences within mean±1.96 SD were not clinically important, the two methods maybe used interchangeably.

In Figure 1, horizontal dashed line at zero difference mark on y-axis represent perfect prediction of intraoperative measurement by the test. Horizontal straight line (labeled as mean) represents mean difference of the test in sizing the aortic annulus when compared with intraoperative measurement. Blue dashed line represents the regression line, which indicates the proportional difference with the intraoperative measurement.

Interpretation of Regression Studies: None of the tests showed significant p value (<0.001), which indicates measurements by all methods were not significantly different from the intraoperative measurement (Table 3).

Test	Mean arithmetic difference	Standard deviation	p Value
TTE	-0.9001	± 2.6	0.6596
3-D TEE	-0.0533	±1.64	0.4866
2-D TEE	-0.0633	±1.69	0.3135
CT (CORONAL)	-3.7067	±1.7	0.5214
CT (SAGITTAL)	-1.6467	±0.9	0.1862
CAAD	-0.936	±0.9	0.3194

Table 3: Summary of Regression Analysis showing Mean Difference between Each Investigation Modality and Intraoperative Measurement and the p Value

DISCUSSION: The precise preoperative assessment of aortic annulus diameter is crucial for optimal valve sizing in patients scheduled for transcatheter aortic valve replacement and is one of the determinates for the procedure outcome. At present, there is no gold standard test for noninvasive assessment of aortic annulus.

Our study included 30 patients of severe AS. All patients underwent 2-dimensional TTE, 2-dimensional TEE, 3-dimensional TEE and MSCT for assessment of aortic annulus preoperatively. Subsequently, intraoperative aortic annulus was measured in all patients. The data was analysed to compare the efficacy of noninvasive preoperative tests to determine the exact aortic annulus measured intraoperatively.

In our study, the noninvasive investigations in the increasing order of correlation with the intraoperative measurements were:

1. CT measurements (sagittal plane).
2. CT measurements (coronal plane).
3. Transthoracic echocardiography.
4. 2-dimensional TEE.
5. 3-dimensional TEE.
6. Calculated average annulus diameter (by CT planimetry).

Although, by both correlation and regression analysis, none of the investigations showed significant (p <0.001) difference with the intraoperative measurements still the differences among them maybe clinically significant in preoperative sizing of valve before TAVI.

Most of the studies, which have compared intraoperative measurements with preoperative echocardiographic and CT measurements concluded that as compared with echocardiographic measurements, dimensions obtained with CT were more correlating with that obtained intraoperatively.

Willmann and colleagues demonstrated good agreement aortic annulus assessment in CT and measurement during aortic valve replacement.[11] In their study, only a plane view of aortic annulus in CT, formally equal to measurements with TEE, was compared to intraoperative data. In a study by Dashkevich and colleagues, CT dimensions were measured with not only single oblique view, but also using planimetry analysis in a 3-dimensional fashion.[8] The CT dimensions by planimetry (CAAD) were compared with TEE and intraoperative measurements as well as to the size of the surgically implanted valve. Among all measurement techniques, CAAD showed the strongest correlation with intraoperative measurements measured with Hegar dilator.

Furthermore, CAAD showed a strong correlation with the size of the surgically implanted aortic valve prosthesis. The correlation of TEE assessed diameter and intraoperative measurements was weaker. Moreover, TEE tended to underestimate aortic annulus dimensions when compared with intraoperative measurements.

In our study, the investigations in 2-dimensional plane (TTE, 2-dimensional TEE and CT measurements in coronal and sagittal plane) when compared among themselves showed better correlation of 2-dimensional TEE with intraoperative measurements than MSCT and TTE measurements. This was against the conclusion drawn by Willmann and colleagues who demonstrated that CT measurements in single oblique plane were better correlating with intraoperative measurements.[11]

In contrast to 2D TEE and single calliper measurements in CT, the planimetry-based CAAD appears to allow for a more comprehensive assessment of the ovoid shape and minimises the dependency of single-view measurement (TEE) on elliptic shape of the aortic annulus.

Few studies have also compared 2-dimensional TEE and 3-dimensional TEE measurements of aortic annulus with the preoperatively obtained measurements from MSCT. These studies have presumed CT planimetry measurements as "gold standard." In a study by Ng et al, 2-dimensional circular, 3-D circular and 3-D planimetered annular and LVOT areas by TEE were compared with MSCT planimetered areas before TAVI. They concluded that annular areas were underestimated by 2-D TEE circular (3.89±0.74 cm2, p <0.001), 3-D TEE circular (4.06±0.79 cm2, p±0.001) and 3-D TEE planimetered annular areas (4.22±0.77 cm2, p <0.001). Three-dimensional TEE planimetered annular and LVOT areas had the best agreement with respective MSCT planimetered areas.[12] This is also in line with our study as both the investigations in which 3-dimensional view of aortic annulus was used to assess the measurements (i.e. 3-dimensional TEE and CT by planimetry) showed better correlation with the intraoperative measurements in contrast to those investigations in which 2 dimensional view of annulus was used (TTE, 2-dimensional TEE and CT measurements in single oblique plane-coronal/ sagittal).

In a study by Tzikas et al, the dimensions of the aortic annulus were measured using TTE, Coronary angiography (CA) and MSCT in 70 patients with severe AS referred for TAVI. Agreement between imaging techniques and interobserver variability was assessed. Like in our study, in their study also the MSCT coronal view provided the largest mean annulus diameter (26.3 mm) followed by CA (24.4 mm), MSCT Mean (23.7 mm), TTE (22.6 mm) and MSCT sagittal (21.8 mm) view. Differences in the annulus measurements were significant. They concluded that there were significant differences in the dimensions of the aortic annulus measured by MSCT, CA and TTE. Interobserver variability for TTE and CA was substantially higher compared with MSCT.[13]

Similarly in a study by David Messika-Zeitoun and colleagues, annulus diameter was measured using TTE, TEE and MSCT in 45 consecutive patients with severe AS referred for TAVI. The TAVI strategy (decision to implant and choice of the prosthesis size) was based on manufacturer's recommendations (Edwards-SAPIEN prosthesis, Edwards Lifesciences, Inc., Irvine, California). They concluded that correlations between methods were good, but the difference between MSCT and TTE or TEE was larger than the difference between TTE and TEE. Measurements of the aortic annulus using TTE, TEE and MSCT were close, but not identical and the method used has important potential clinical implications on TAVI strategy.[7] In the absence of gold standard, a strategy based on TEE measurements provided good clinical results. However, unlike in our study, the data was not compared with exact intraoperative measurements.

Computed tomographic measurements were done in two planes (coronal and sagittal). Comparison of the coronal and sagittal diameters showed that aortic annulus is an oval structure and not a round one.

It is unclear whether the systematic, but small difference between annulus measurements by means of TEE and CAAD in CT (-1.078±1.8 mm) may have any clinical relevance. The routinely practiced oversizing of the prosthesis by up to 20% might probably make the small differences in measured aortic annular diameters using TEE or CT clinically negligible. The aortic annulus measurement by means of two dimensional (2D) methods (TEE, TTE, single oblique view in CT) appears to be restricted to a single plane or a limited field of view. A single plane measurement of oval aortic annulus can lead to significant differences in assessment results while using these imaging modalities. The approach of three-dimensional (3D) imaging, as known for CT, magnetic resonance imaging or 3D echocardiography allows complete morphologic analysis of aortic valve structures and seems to be preferable for preoperative valve sizing. Compared with 2D TEE, 3D TEE was demonstrated to achieve the best agreement with annulus measurement by intraoperative means.

Further studies will be needed to prove the clinical relevance of depicted differences between TEE and CT for the clinical outcome. Still CAAD assessment by CT should be considered in preoperative valve sizing because of its good agreement with the true dimensions of the aortic annulus. This is supported by recent findings that compared with 2D TEE and other CT-based measurement techniques; CAAD most strongly correlates with the area of the unfolded stent in patients with balloon-expandable TAVI.[14] Devices for TAVI are circular and not ovoid when viewed axially and as recently demonstrated the Edwards SAPIEN transapical valve prosthesis (Edwards Lifesciences Inc.) expands to an almost circular shape in most patients.[15] Thus, it may be assumed that balloon expandable TAVI alters the configuration of the native annulus, analogous to introducing the valve sizers into the ovoid annulus.

LIMITATIONS:

1. The intraoperative measurements were done after decalcification of aortic valve and resection of the valve leaflets. The deviation from the noninvasive measurements with TEE and CT on the intact valve structure should still remain minimal while annulus calcifications were included into the measurements.
2. While we could demonstrate solid statistical significance within our sample size of 30 patients, further studies in a larger patient cohort maybe reasonable for more clinical evidence.

CONCLUSION:

1. Noninvasive investigations in which aortic annuls was measured in 3-dimensional view (CT-based aortic annulus measurement employing calculated average diameter assessment by means of planimetry and 3-dimensional TEE) showed better correlation with intraoperative measurement of aortic annulus.
2. CT-based aortic annulus measurement employing calculated average diameter assessment by means of planimetry seems to provide adequate dimensions most similar to operative measurements.
3. The CAAD approach may minimise the dependency of single-view CT measurement on the elliptic shape of the aortic annulus and appears to be a feasible alternative for aortic annulus assessment in terms of candidates' selection for transcatheter aortic valve replacement.

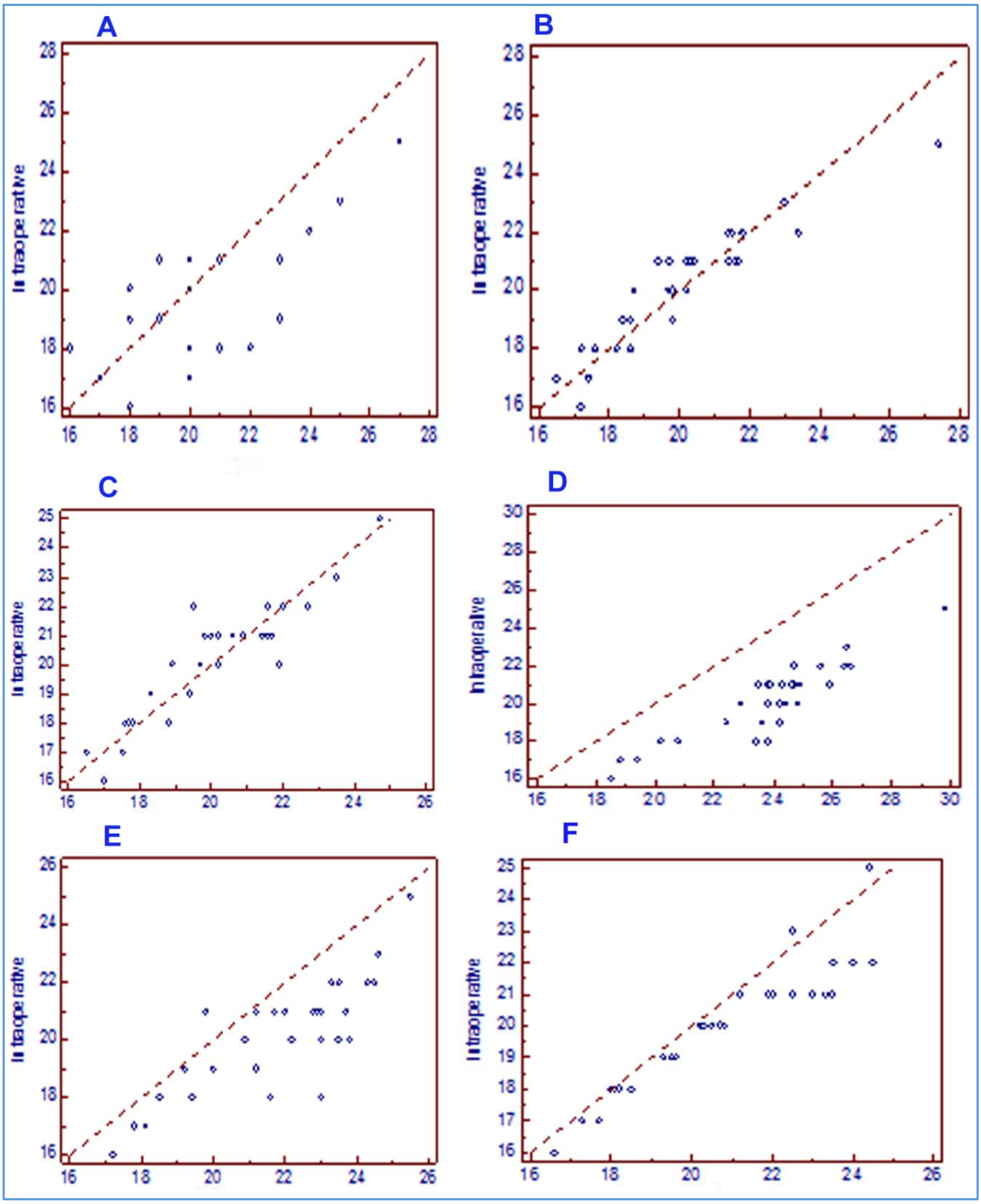

Fig. 1: Graph Depicting Correlation between Aortic Annulus Measurement by (a) TTE (b) 3D TEE (c) 2D TEE (d) CT Coronal View (e) CT Sagittal View and (f) CT Planimetry-CAAD and Intraoperative Measurements (in mm) by Spearman's Rho Coefficient of Rank Correlation. Dotted Line Represents Line of Equity

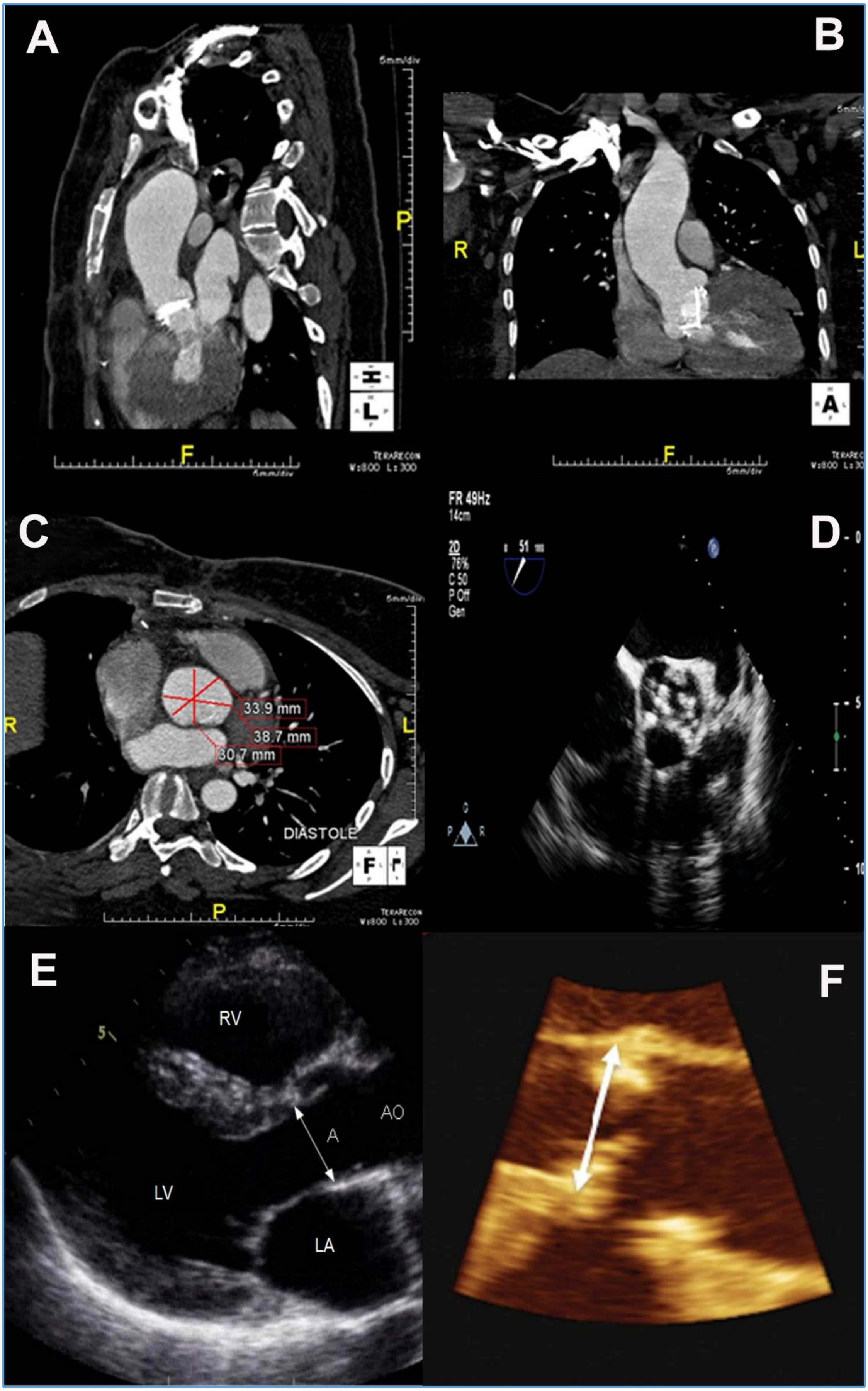

Fig. 2: CT and Echocardiographic Images showing Measurement of Aortic Annulus: a) Sagittal View - CT Angiography b) Coronal View - CT Angiography c) CAAD Measurement by Planimetry Method d) 2-D Transesophageal Measurement e) 2-Dimensional Transthoracic Echocardiography f) 3-Dimensional Transesophageal Echocardiography

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