Application of Three-Dimensional Transesophageal Echocardiography in Preoperative Evaluation of Transcatheter Aortic Valve Replacement

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Research article

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Abstract

Background

Analysing the accuracy of 3D-TEE in preoperative evaluation of TAVR compared with CT when the error led by inconsistent software and method has been eliminated and the representativeness of sample has been improved, and exploring the influence of aortic root calcification on the accuracy of 3D-TEE in aortic annulus evaluations.

Methods

Part I: 45 of 233 patients who underwent TAVR in the department of cardiovascular surgery in Xijing hospital from January 2016 to August 2019 were retrospectively studied. Mimics and multiplanar reconstruction method were used for evaluation based on 3D-TEE and CT. Annulus diameter - area derived (Da), annulus diameter - perimeter derived (Dp), annulus mean diameter, the left ventricular outflow tract (LVOT) diameter-Dp, the sinus tube junction (STJ) diameter-Dp and aortic sinus diameter were compared and analyzed.

Part ii: 31 of 233 patients whose 3D-TEE and CT data were well preserved and in the required format were included. HU450 and HU850 were used as indicators to measure the severity of calcification, and spearman rank correlation and ROC curve was used to analyze the correlation between aortic root calcification and accuracy of 3D-TEE in aortic annulus measurement.

Results

The measurement results based on 3D-TEE were significantly lower than those of CT ($p<0.05$), except for the STJ diameter-Dp in diastole ($p=0.11$). The correlation coefficient of the two groups was 0.699 ~ 0.954 ($p < 0.01$), which also indicated a significant correlation between the two groups.Bland-Altman plot showed that the ordinate values were mostly within the 95% consistency limit, the consistency of the two groups was good. By establishing the linear regression equation, the two groups can be inferred from each other. Spearman rank correlation analysis and ROC curve analysis showing that the influence of aortic calcification on the accuracy of 3D-TEE annulus evaluation was limited.

Conclusions

Whlie evaluation based on 3D-TEE underestimated the results, we can deduce CT results from 3D-TEE as they obtain considerable correlation and consistency. Calcification in the aortic sinus did not affect the accuracy of 3D-TEE annulus evaluation.

Trial registration

Name: Surgery and Transcatheter Intervention for Structural Heart Diseases

Number: NCT02917980

URL : https://clinicaltrials.gov/ct2/results?term=NCT02917980

Introduction

Transcatheter aortic valve replacement (TAVR) has become the treatment of choice for severe aortic diseases. Its safety and efficacy have been widely demonstrated in patients who are inoperable or at medium to high risk for surgery (1, 2). The US Food and Drug Administration has recently approved the use of self-expanding valve Evolut R and Evolut PRO systems (Medtronic Inc., Minneapolis, USA) and balloon-expandable Valve Sapien 3 (Edwards Lifesciences Inc., Irvine, USA) for the treatment of severe aortic stenosis (AS) in patients at low risk based on the results of large sample multi-center randomized controlled trials(3, 4), which is a milestone for the development of this technology.

As direct visualization of aortic root is not available during TAVR procedure, accurate preoperative evaluation of aortic root is of critical importance to reduce occurrence of complications such as paravalvular aortic regurgitation, valve embolization, coronary obstruction, atrioventricular block and annulus rupture, et al.

Computed tomography (CT) is currently the standard of care for preoperative evaluation as it offers more obvious contrast between the vascular and non-vascular structures and facilitate accurate measurement(5)(Fig. 1). However, the application of CT is contraindicated for patients who are suffered from renal dysfunction, allergic to contrast agents or unsuitable for CT for some other reasons.

Three-dimensional transesophageal echocardiography (3D-TEE) has been proposed as an alternative method as it is harmless to human (Fig. 1). However, accurate 3D-TEE imaging has very strict requirements on respiratory heart rate control and was susceptible to calcification and other impurities, there is no standard measurement method based on 3D-TEE now. Previous researches showed measurements based on 3D-TEE tend to underestimate the aortic root (6) and resulted in a higher occurrence of paravalvular regurgitation (7). However, most of the researches mentioned above employed different software and methods for the evaluation of CT and 3D-TEE resources, which may contribute to error. Besides, the studies are mainly focused on the cases of severe aortic stenosis, while the indication of TAVR has already been extended to aortic regurgitation (AR) patients (8–10), there is insufficient evidence regarding the accuracy of 3D-TEE measurements of TAVR patients including AS and AR compared with CT using the same software and method.

For the above-mentioned reasons, the aim of this study is to evaluate the accuracy of 3D-TEE in preoperative measurement of AS as well as AR patients compared with CT using the same software and method, and try to find out the factors that may influence it.

Methods

Patients

We retrospectively collected information of 233 patients who underwent TAVR during January 2016 to August 2019 in the department of cardiovascular surgery, Xijing hospital. 45 patients whose preoperative CT and intraoperative 3D-TEE data were attainable and available were included in our study, other patients were excluded because of insufficient image acquisition or inappropriate storage format of 3D-TEE.

Image acquisition and evaluation

Preoperative CT images were stored in the format of Digital Imaging and Communications in Medicine (DICOM), which is the international standard format of medical images and related information. After the data was imported into Materialise Mimics 21.0 (Leuven, Belgium), a set was composed. In addition to the original axial plane, the software automatically reconstructed the sagittal and coronal plane. To make sure the three lowest points of the aortic sinus simultaneously appeared in the axial plane by adjusting the location of the planes, we got the virtual annulus plane. After manually delineating the contour of the annulus, the information we needed such as area-derived diameter of annulus (Annulus-Da), perimeter-derived diameter of annulus (Annulus-Dp) and mean diameter[1] of annulus (Annulus-Mean) can be collected. Using the same method, other measurements such as perimeter-derived diameter of Left ventricular outflow tract (LVOT-Dp), perimeter-derived diameter of sinotubular junction (STJ-Dp), and sinus of Valsalva (SOV) diameters can be also obtained.

3D-TEE data was obtained immediately before operation, the Philips Medical ultrasound system (iE33) and probe (X7-2t) were used. Images were also stored in DICOM and imported into QLAB software (Philips Medical Systems) and viewed in 3DQ mode. Images in the proper phase were chosen and exported in cartesian DICOM (3DDCM) format. Finally, the exported images were opened with Mimics software and the rest processes were the same as CT.

The severity of valve calcification was evaluated using HU450 or HU850, which were defined to be the volume of the part whose CT value is more than 450 or 850 HU, are commonly used in preoperative evaluation of TAVR patients. These two factors can be evaluated in Mimics software.

Statistical analysis

Data were firstly tested using the Kolmogorov- Smirnov test. Categorical variables was presented as number (percentage). If normal distribution was confirmed, continuous data are presented as mean ±SD, a paired two-sided Student's t test, as well as Pearson correlation coefficients and linear regression were used for comparison of measurements between the two methods. For those didn't obey to normal distribution, continuous data are presented as median (P25, P75), the differences between the two methods were evaluated using the Wilcoxon signed-rank test, the correlations were calculated using the Spearman rank test, normal transformation will be used if needed. Bland-Altman plots were used to calculate the concordance between 3D-TEE and CT. To explore the influence of calcification on the differences between the two methods, a Spearman rank test was conducted with the ROC curves obtained. Statistical significance was set at $p<0.05$. Data analyses were conducted with SPSS 23 (SPPS Inc., Chicago, USA).

[1] $\text{Mean diameter}=\frac{\text{maximum diameter}+\text{minimal diameter}}{2}$

Results

patients

The patients were 67.2 ± 7.5 years old, of which 35(77.8%)were male, through preoperative transthoracic echocardiography, 10（22.2%) were diagnosed as pure AS, 17(37.8%) as pure AR and 18(40.0%) as aortic stenosis with regurgitation. 44 of 45 patients received TAVR except for 1 who gave up because of a severely narrowed LVOT, 22(48.9%) of them went through transapical approaches using the J-valve (Jie Cheng Medical ltd., Su Zhou, China), the others went through transfemoral approaches using the Venus-A valve (QI Ming Medtech ltd, Hang Zhou, China) (Fig. 2). 1(2.2%) patient converted to thoracotomy because of valve migration and 1(2.2%) patient with unstable blood pressure turn to ECMO, the other 42 cases were successfully completed (Table 1).

Table 1
Demographic and Clinical Baseline Characteristics

Age(years)	**67.2 ± 7.5**
Male	35(77.8%)
STS-PROM(%)	4.97(3.35,5.61)
Logistic EuroSCORE II score(%)	11.30(3.48,13.67)
Hematocrit	0.40(0.38,0.45)
WBC ($\times 10^9$)	7.58(5.48,9.32)
Platelet($\times 10^6$)	188.58(151.50,214.00)
Creatinine(umol/L)	91.64(69.00,104.00)
Left ventricular ejection fraction(%)	44.36(34.50,54.50)
Hypertension	24(53.3%)
Cerebrovascular Disease	16(35.5%)
Diabetes	12(26.7%)
Chronic Lung Disease	27(60.0%)
Classification-NYHA	43(95.6%)
Atrial fibrillation	11(24.4%)
Coronary artery disease	13(28.9%)
Aortic stenosis	10(22.2%)
Aortic regurgitation	17(37.8%)
Aortic stenosis with regurgitation	18(40.0%)
Transapical	22(48.9%)
Transfemoral	22(48.9%)
Turn to ECMO	1(2.2%)
Trans to surgery	1(2.2%)

Annulus And Lvot Measurements

All the 45 patients' CT and 3D-TEE images were suitable for annulus and LVOT evaluation, and normal distributions were confirmed. Compared to CT references, measurements derived from 3D-TEE data obviously underestimate the diameter of aortic annulus and LVOT :annulus-Da in systole(24.52 ± 2.36 VS 25.55 ± 2.59 mm, $P < 0.01$); annulus-Dp in systole(25.69 ± 2.56 VS 26.36 ± 2.67 mm, $P < 0.01$); annulus-Mean in systole (25.24 ± 2.47 VS 25.93 ± 2.61 mm, $P < 0.01$); LVOT-Dp in systole(27.57 ± 3.91 VS 28.48 ± 3.92 mm, $P < 0.01$); annulus-Da in diastole(23.54 ± 2.86 VS 24.86 ± 2.61 mm, $P < 0.01$); annulus-Dp in diastole(25.11 ± 2.85 VS 26.02 ± 2.70 mm, $P < 0.01$); annulus-Mean in diastole(24.14 ± 2.90 VS 25.44 ± 2.63 mm, $P < 0.01$); LVOT-Dp in diastole(27.37 ± 4.73 VS 29.79 ± 4.50 mm, $P < 0.01$) (Table 2). The linear regression and correlation coefficients (range from 0.70 to 0.95) showed the two measurement were closely related to each other ($p < 0.01$) (Fig. 3), and the Bland-Altman analysis showed they were in good agreements (Fig. 4).

Table 2
Comparison and correlation analysis of 3D-TEE and CT measurement of annulus and LVOT

Measurement	Sample size	3D-TEE	CT	CT-TEE	p	Correlation	
						R	P
Systole							
Annulus-Da	45	24.52 ± 2.36	25.55 ± 2.59	1.03 ± 0.98	<0.01	0.93	<0.01
Annulus-Dp	45	25.69 ± 2.56	26.36 ± 2.67	0.67 ± 1.13	<0.01	0.91	<0.01
Annulus-Mean	45	25.24 ± 2.47	25.93 ± 2.61	0.69 ± 1.20	<0.01	0.89	<0.01
LVOT-Dp	45	27.57 ± 3.91	28.48 ± 3.92	0.91 ± 2.19	<0.01	0.84	<0.01
Diastole							
Annulus-Da	45	23.54 ± 2.86	24.86 ± 2.61	1.32 ± 1.46	<0.01	0.86	<0.01
Annulus-Dp	45	25.11 ± 2.85	26.02 ± 2.70	0.91 ± 1.28	<0.01	0.90	<0.01
Annulus-Mean	45	24.14 ± 2.90	25.44 ± 2.63	1.30 ± 1.63	<0.01	0.83	<0.01
LVOT-Dp	45	27.37 ± 4.73	29.79 ± 4.50	2.42 ± 3.59	<0.01	0.70	<0.01

Sov And Stj Measurements

9 patients with bicuspid aortic valve were excluded from the SOV measurement because the sample size was too small. 2 patients in systole of 3D-TEE and 1 patient in diastole of 3D-TEE couldn't afford for STJ evaluation because of image insufficiency. The data were treated as abnormal distribution as some of them didn't obey to normal distribution according to the Kolmogorov- Smirnov test. Except for the STJ-Dp in diastole, which didn't show a statistic difference ($p = 0.11$) between the two methods, other measurements demonstrated that the values from 3D-TEE significantly smaller than those of CT's ($P < 0.01$) (Table 3). The correlation coefficients calculated by Spearman rank test ranged from 0.89 to 0.95 ($p < 0.01$), showed a tight correlation between the groups(Table 4). Bland-altman study showed that the ordinate values were mostly within the 95% consistency limit, the consistency of the two groups was good (Fig. 5). After the reciprocal transformation of the data, all the data approximately obey to the normal distribution, the transformed data were used for linear regression analysis (Fig. 6).

Table 3
Comparison of 3D-TEE and CT measurement of STJ and SOV

Measurement	Sample size	3D-TEE	CT	p
Systole				
STJ-Dp	43	31.89(29.00,38.79)	33.41(31.23,39.45)	<0.01
SOV-L	36	35.63(31.04,42.51)	36.28(32.75,46.08)	<0.01
SOV-R	36	34.49(31.75,42.03)	35.51(32.26,45.66)	<0.01
SOV-N	36	34.98(31.73,42.95)	37.13(34.05,45.83)	<0.01
Diastole				
STJ-Dp	44	32.59(29.51,40.23)	32.77(30.77,39.65)	0.11
SOV-L	36	34.71(31.43,41.51)	35.53(32.37,43.24)	<0.01
SOV-R	36	34.09(30.37,41.61)	33.87(31.56,44.60)	<0.01
SOV-N	36	33.97(30.63,42.48)	35.70(32.59,45.08)	<0.01
SOV-L: left-coronary sinus of Valsalva SOV-R: right-coronary sinus of Valsalva SOV-N: non-coronary sinus of Valsalva				

Table 4
Correlation analysis of 3D-TEE and CT measurement of STJ and SOV

Measurement	Sample	3D-TEE	CT	Correlation		1/TEE*	1/CT*	Correlation	
				R	P			R	P
Systole									
STJ-Dp	43	31.89(29.00,38.79)	33.41(31.23,39.45)	0.95	<0.01	0.030 ± 0.006	0.029 ± 0.005	0.97	<0.01
SOV-L	36	35.63(31.04,42.51)	36.28(32.75,46.08)	0.93	<0.01	0.028 ± 0.005	0.026 ± 0.005	0.95	<0.01
SOV-R	36	34.49(31.75,42.03)	35.51(32.26,45.66)	0.95	<0.01	0.028 ± 0.005	0.027 ± 0.005	0.95	<0.01
SOV-N	36	34.98(31.73,42.95)	37.13(34.05,45.83)	0.92	<0.01	0.028 ± 0.005	0.026 ± 0.004	0.95	<0.01
Diastole									
STJ-Dp	44	32.59(29.51,40.23)	32.77(30.77,39.65)	0.86	<0.01	0.030 ± 0.006	0.029 ± 0.005	0.93	<0.01
SOV-L	36	34.71(31.43,41.51)	35.53(32.37,43.24)	0.9	<0.01	0.028 ± 0.005	0.027 ± 0.005	0.94	<0.01
SOV-R	36	34.09(30.37,41.61)	33.87(31.56,44.60)	0.83	<0.01	0.029 ± 0.005	0.027 ± 0.005	0.96	<0.01
SOV-N	36	33.97(30.63,42.48)	35.70(32.59,45.08)	0.7	<0.01	0.029 ± 0.005	0.027 ± 0.004	0.93	<0.01

SOV-L: left-coronary sinus of Valsalva SOV-R: right-coronary sinus of Valsalva SOV-N: non-coronary sinus of Valsalva

*The data approximate obey to normal distribution after inverse transformation, so they were used for linear regression analysis.

Annulus Measurement Difference And Calcification

The accuracy of evaluation of HU450 and HU850 depended on the consistency of contrast concentration during CT examinations in different patients. 31 of 45 patients whose contrast concentration were approximately same were included in the research.

There were no statistical correlation between annulus measurement difference and HU450 ($p = 0.18$~0.99) or HU850 ($p = 0.41$~0.83) (Table 5). Defining value differences between 3D –TEE and CT ≥ 1 mm as positive, and calcification as the predictive factor, the ROC curves can be delineated, the area under curve were 0.51 ± 0.11 to 0.69 ± 0.10 for HU450 and 0.51 ±

0.10 to 0.65 ± 0.10 for HU850, both showed limited value for calcification as a factor to predict the accuracy of 3D-TEE evaluation (Table 6) (Fig. 7).

Table 5
ROC analysis of aortic root calcification and accuracy of 3D-TEE measurement(CT measurement as the golden standard)

Measurement	Samlpe	|3D-TEE-CT|	HU450	HU850	Correlation(P)	
					HU450	HU850
Systole						
Annulus-Da	31	1.06(0.37,1.61)	431.62(6.61,1109.81)	95.80(0.56,479.92)	0.18	0.41
Annulus-Dp	31	0.87(0.45,1.53)			0.99	0.80
Annulus-Mean	31	1.01(0.47,1.30)			0.91	0.70
Diastole						
Annulus-Da	31	1.77(0.97,2.28)			0.96	0.83
Annulus-Dp	31	1.22(0.48,1.84)			0.76	0.75
Annulus-Mean	31	1.72(0.92,2.35)			0.75	0.80

Table 6
Correlation analysis of aortic root calcification and accuracy of 3D-TEE measurement(CT measurement as the golden standard)

Measurement	Sample	|3D-TEE-CT|	HU450	HU850	Aera under curve	
					HU450	HU850
Systole						
Annulus-Da	31	1.06(0.37,1.61)	431.62(6.61,1109.81)	95.80(0.56,479.92)	0.69 ± 0.10	0.65 ± 0.10
Annulus-Dp	31	0.87(0.45,1.53)			0.54 ± 0.108	0.57 ± 0.11
Annulus-Mean	31	1.01(0.47,1.30)			0.51 ± 0.110	0.51 ± 0.11
Diastole						
Annulus-Da	31	1.77(0.97,2.28)			0.58 ± 0.108	0.60 ± 0.11
Annulus-Dp	31	1.22(0.48,1.84)			0.52 ± 0.107	0.51 ± 0.11
Annulus-Mean	31	1.72(0.92,2.35)			0.60 ± 0.126	0.58 ± 0.12

Discussion

Preoperative evaluation derived from CT based on the multi-plane reconstruction function of measurement software such as 3-mensio is regarded as the golden standard for TAVR patients now, obvious contrast between the lumen and the myocardium/vascular wall enable its significant performance in distinguish vascular and non-vascular structures. However, the use of contrast and exposure to ionizing radiation limit its application in some special patients who are allergic to contrast agents or suffered from renal insufficiency. 3D-TEE was expected to act as an alternative method for these patients. Different from CT, there is no mature or uniform TEE - based preoperative evaluation method. 2D-TEE was the initial resource, however, as the structures been measured were usually oval instead of perfectly round, this measurement tended to severely underestimate the results. With the popularization of 3D-TEE, it replaced 2D-TEE and was widely used in preoperative evaluation of TAVR patients. Arnold (11) used the q-lab (Philips Medical Systems) to measure the aortic annulus and LVOT by the same multi-plane reconstruction method as CT. Omar (12) evaluated the aortic root by off-label using of mitral valve measurement software Mitral Valve Quantification (Philips Medical Systems). A semi-automated software specifically designed for aortic root was used by Mediratta and his colleagues (13), and two automated software Aortic Valve Navigator (Philips Medical Systems) and eSieValvesTM (Siemens Medical) had been applied by Edgard(14) and Nahoko(15), respectively. Despite improvements in software, the above studies generally showed that measurement based on 3D-TEE were still significantly smaller than those based on CT. We considered that the inconsistency between the methods and software might be important factors contributed to the measurement differences. Therefore, we chose the same Mimics software to evaluate CT and 3D-TEE images in order to eliminate the possible error. However, the final results did not show as we expected. The difference had not been significantly reduced. Even though, good correlation and agreement between them still enabled 3D-TEE to be used as preoperative imaging data in TAVR patients contraindicated for CT examination. Figure 2 shows the regression equation between CT and 3D-TEE measurements regarding to annulus and LVOT.

Severe calcification will significantly deteriorate the image quality of 3D-TEE because of the artifact generated by it, thus impede the measurement and reduce the accuracy in theory. However, our research failed to come to the expected conclusion. Calcification didn't show an obvious correlation to the differences between 3D-TEE and CT measurements of annulus diameters. The value of HU450 and HU850 in predicting the discrepancy was also limited from the analysis of ROC curve. In fact, in our research we found that calcification was not always a negative factor, its highlighting signal can sometimes help to distinguish valve leaflet and locate annulus, and this may partly account for the results.

What's new about our research is not only that we used the same software and method for 3D-TEE and CT measurement, but also we had expanded the patient sample and measurement parameters. Due to the lacking of calcification which was essential for the bioprosthetic valves to anchor in the early cases, pure AR patients were once considered as contraindicated for TAVR (16). In recent years, CoreValve (Medtronic Inc., Minneapolis, USA) (17) and SAPIEN XT (Edwards Lifesciences Inc., Irvine, USA) (18)with the help of some special designs, and some new valves dedicated for AR patients such as JenaValve (JenaValve Technology GmbH, Munich, Germany) (19), J-valve (Jie Cheng Medical ltd., Su Zhou, China) (20), and ACURATE series (Symetis SA, Ecublens, Switzerland)(21, 22) had started to be used for the treatment of them. To our knowledge, this is one of the first studies with pure AR patients included. Preoperative evaluation of TAVR mainly included diameter measurements of aortic annulus, LVOT, SOV, STJ and ascending aorta(AAO), and assessment of coronary artery height, left ventricular aortic angle, valve type and calcification, optimal angiographic projection angle and peripheral vascular anatomy, etc. Each parameter plays an important role in strategy making. Accurate acquisition of diameters of annulus and other structures can help to choose the most appropriate bioprosthesis valve and the best deployment area to prevent complications such as valve migration and PVL. Coronary height and SOV volume are critical indicators to judge the risk of myocardial infarction. Left ventricular aorta angle and peripheral blood vessel evaluation are essential in selection of a better approach and the optimal angiographic projection angle enables the performers to get the best surgical vision. Different from the previous researches which mainly focused on annulus, we had also compared the measurement of LVOT、SOV and STJ, and the results showed 3D-TEE can be used as an alternative for their evaluation.

How to reach the most accurate preoperative evaluation has always been the most concerned issue. In addition to making full use of image resources, the emergence of 3D printing technology provides new ideas for us. Through in vitro reconstruction of patient-specific aortic root model and precise presentation of anatomical structure, 3D printing model has showed its significant role in preoperative evaluation of TAVR patients. In the future, with the development of 3D printing materials, and the combination with the finite element analysis technology, we look forward to select the best operation strategy and forecast operation results by computer simulation before operation, so as to further improve success rate and reduce the risk of complications.

Study Limitations

This is a retrospectively study in our single center, the implanted J-valve and Venus-A valve are different from prosthetic valves used in other countries. Besides, due to the limitations such as small sample size, part of the STJ and SOV data do not follow normal distribution and cannot be used for regression equations establishment and consistency analysis, these may have weaken the representativeness and persuasiveness of the results.

Conclusion

High correlations and good agreements between the two measurements enable 3D-TEE to be an appropriate alternative for TAVR patients who cannot choose CT as the image resource for preoperative individualized decision making. Difference between 3D-TEE and CT measurements still exist with the application of same software and method, which has little thing to do with the severity of calcification. Other factors which dominate the difference needed to be explored.

Abbreviations

TAVR
transcatheter aortic valve replacement
CT
computed tomography
3D-TEE
three-dimensional transesophageal echocardiography
AS
aortic stenosis
AR
aortic regurgitation
DICOM
digital imaging and communications in medicine
Annulus-Da
area-derived diameter of annulus
Annulus-Dp
perimeter-derived diameter of annulus
Annulus-Mean
mean diameter of annulus
LVOT-Dp
perimeter-derived diameter of Left ventricular outflow tract
STJ-Dp
perimeter-derived diameter of sinotubular junction
SOV
sinus of Valsalva

Declarations

Ethics approval and consent to participate

The ethics committee of Xijing hospital approved the study, and all patients gave written informed consent for participating in the study. The consent obtained from study participants was written.

Consent to publish

All authors consent to publish.

Availability of data and materials

The study protocol was approved by the ethics committee of Xijing Hospital (Approval Number: KY20150205-1) and registered in the ClinicalTrials.gov Protocol Registration System (NCT02917980).

Competing interests

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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Authors' Contributions

Ding Peng and Xu Chennian contributed equally to this work. Ding Peng and Yang Jian designed the study, collected, analyzed and interpreted the data. Xu Chennian acquired, analyzed and interpreted data, revised the manuscript. Liu Yang, Tang Jiayou, Jin Ping, Lanlan Li, Ma Yanyan and Lu Linhe acquired the data and revised the manuscript. All authors read and approved the final manuscript.

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Figures

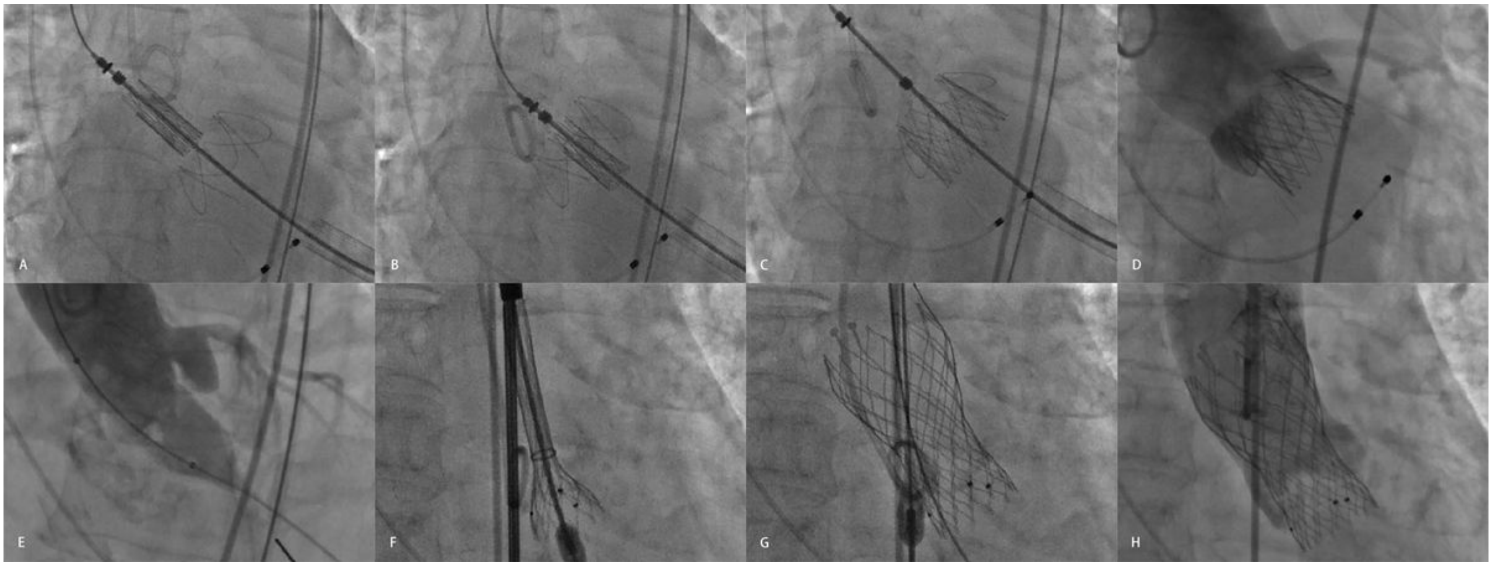

Figure 1

Measurement of aortic root. (A. Annulus based on CT. B. LVOT based on CT. C. STJ based on CT. D. SOV based on CT. E. Annulus based on 3D-TEE. F. LVOT based on 3D-TEE. G. STJ based on 3D-TEE. H. SOV based on 3D-TEE.)

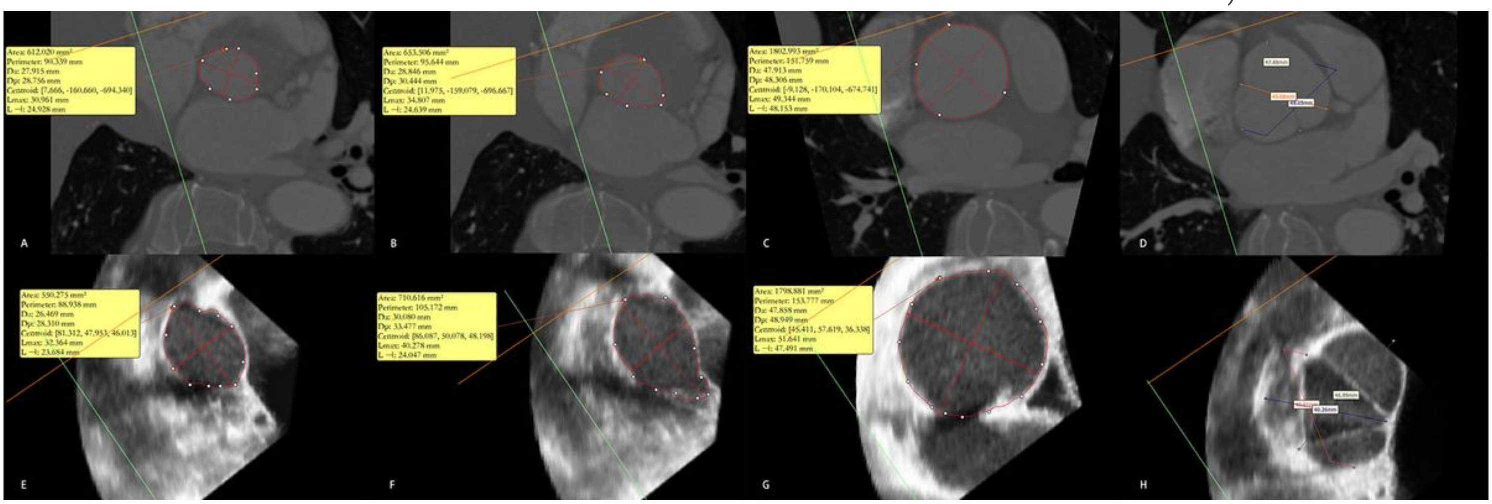

Figure 2

Steps of TAVR in Xijing hospital. (A-D. Using of J-valve through transapical approach. E-H. Using of Venus-A valve through transfemoral approach.)

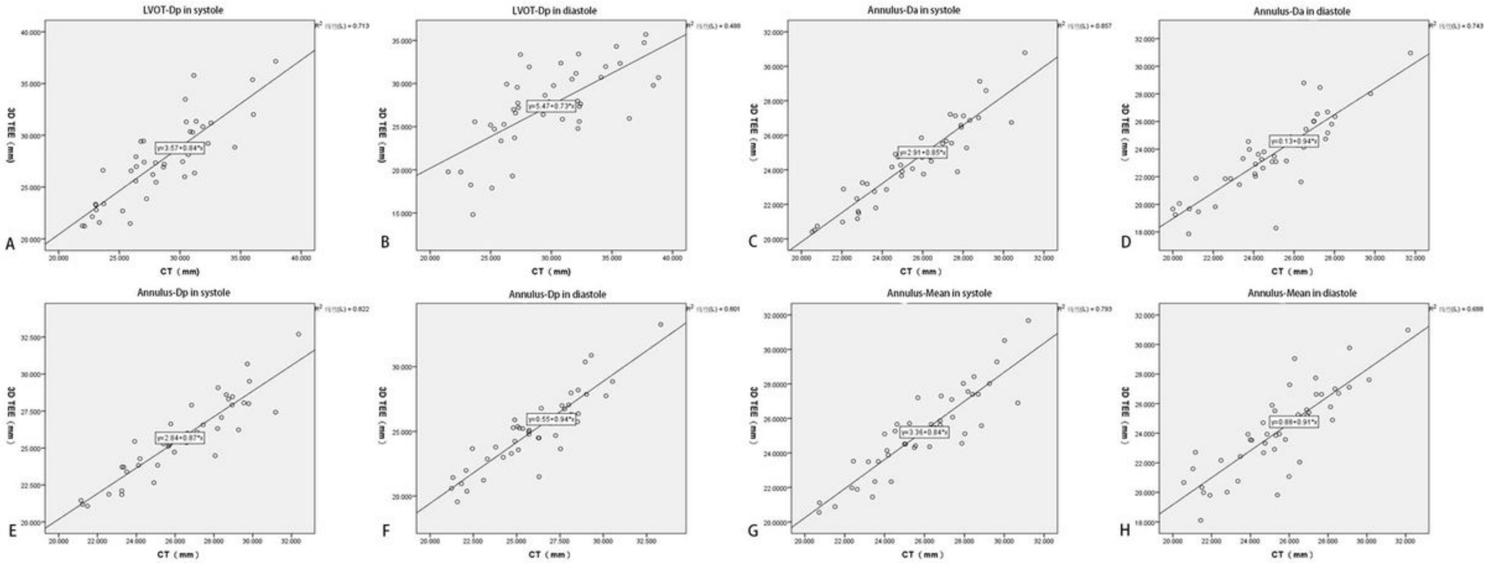

Figure 3

Linear regression showing high correlations between CT and 3D-TEE measurements of LVOT and annulus. (A. LVOT-Dp in systole. B. LVOT-Dp in diastole. C. Annulus-Da in systole. D. Annulus-Da in diastole. E. Annulus-Dp in systole. F. Annulus-Dp in diastole. G. Annulus-Mean in systole. H Annulus-Mean in diastole.)

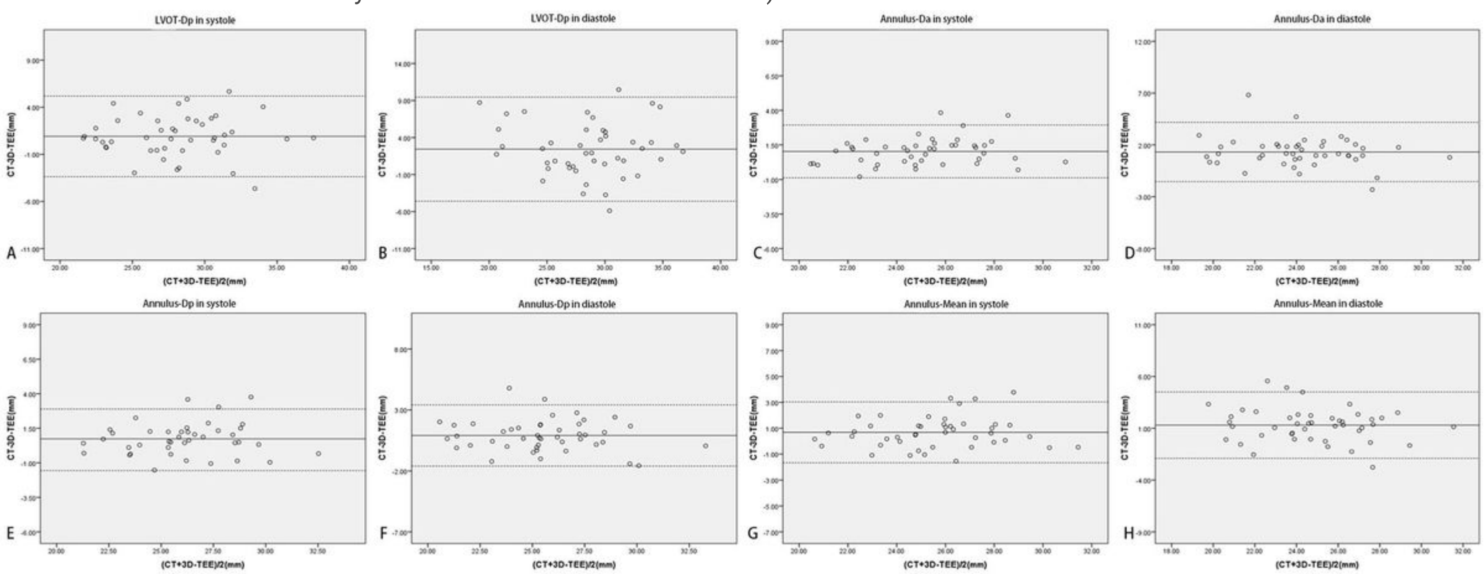

Figure 4

Bland-Altman plot showing good agreement between CT and 3D-TEE measurements of LVOT and annulus. (A. LVOT-Dp in systole. B. LVOT-Dp in diastole. C. Annulus-Da in systole. D. Annulus-Da in diastole. E. Annulus-Dp in systole. F. Annulus-Dp in diastole. G. Annulus-Mean in systole. H Annulus-Mean in diastole.)

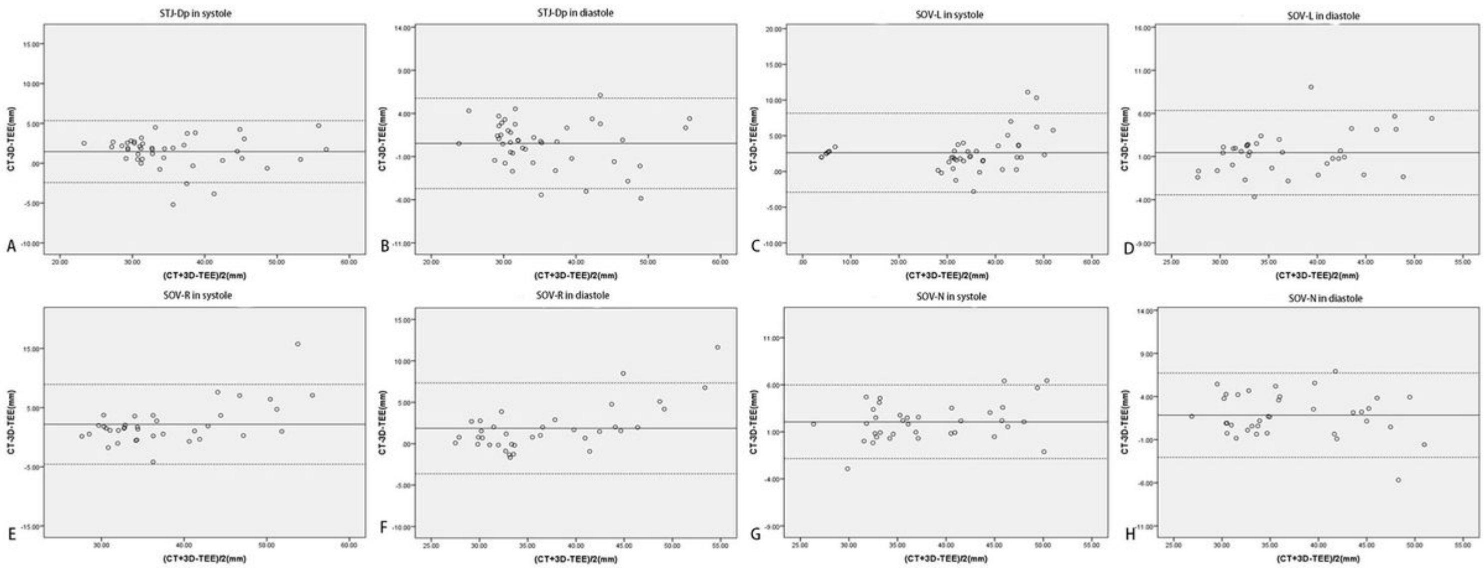

Figure 5

Bland-Altman plot showing good agreement between CT and 3D-TEE measurements of STJ and SOV. (A. STJ-Dp in systole. B. STJ-Dp in diastole. C. SOV-L in systole. D. SOV-L in diastole. E. SOV-R in systole. F. SOV-R in diastole. G. SOV-N in systole. H. SOV-N in diastole.)

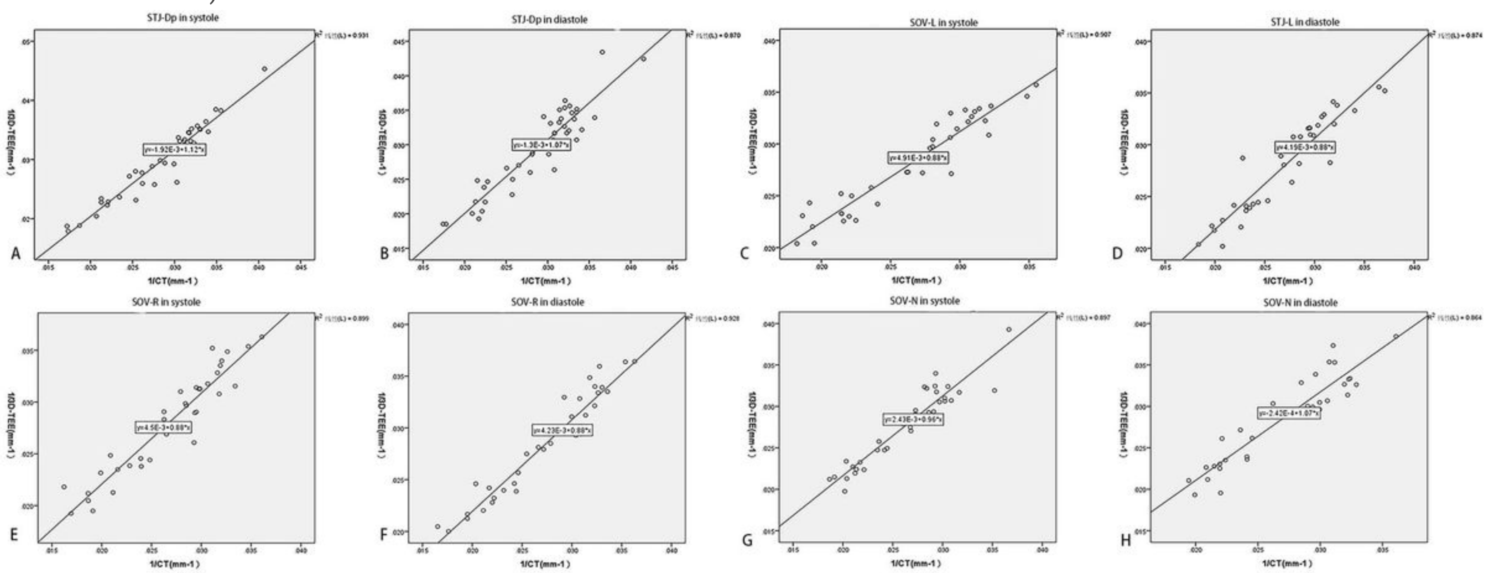

Figure 6

After the reciprocal transformation of the CT and 3D-TEE measurements of STJ and SOV, all the data approximately obey to the normal distribution, Linear regression showing high correlations between. (A. STJ-Dp in systole. B. STJ-Dp in diastole. C. SOV-L in systole. D. SOV-L in diastole. E. SOV-R in systole. F. SOV-R in diastole. G. SOV-N in systole. H. SOV-N in diastole.)

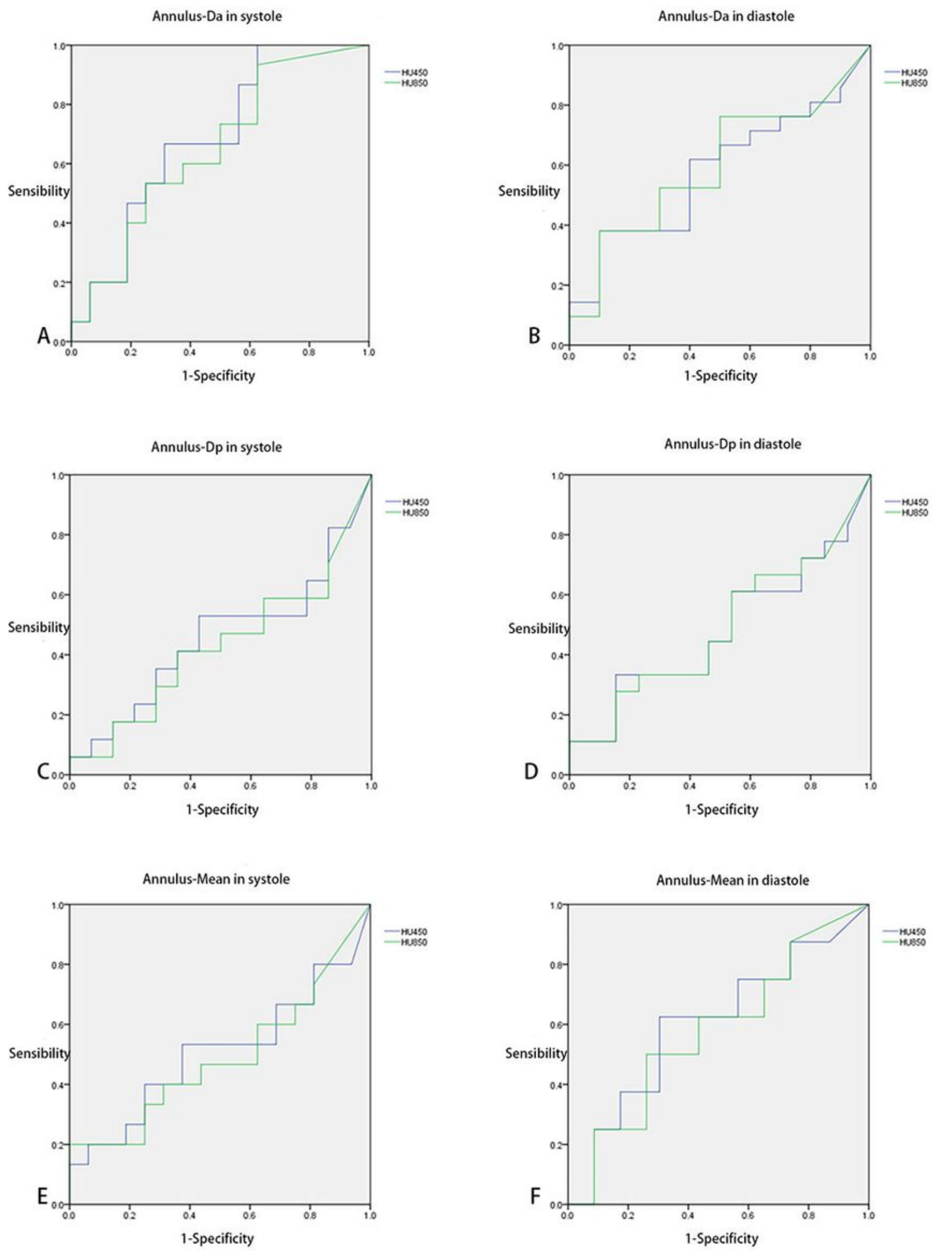

Figure 7

ROC curve showed limited value of calcification in predicting annulus measurement difference (positive was defined as difference ≥1mm)(A. Da in systole. B. Dp in systole. C. Mean in systole. D. Da in diastole. E. Dp in diastole. F. Mean in diastole)