Three-dimensional imaging of the aortic valve geometry for prosthesis sizing prior to transcatheter aortic valve replacement

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Transcatheter aortic valve replacement (TAVR) is established as an alternative treatment option in patients with symptomatic aortic valve stenosis at high risk for cardiovascular surgery and has shown superiority over conservative management in inoperable patients [1,2]. Noninvasive imaging of the aortic valve (AV) geometry plays a central role in TAVR because accurate determination of aortic annular diameters is crucial for appropriate prosthesis sizing [3–5]. Current guidelines define multislice computed tomography (MSCT) with three-dimensional (3D) reconstruction of aortic root geometry as the gold standard for pre-procedural patient selection despite MSCT inherits important limitations [8].

Theoretically, 3D transesophageal echocardiography (3DTEE) allows a precise determination of the AV geometry equal to MSCT, but prospective studies comparing 3DTEE with MSCT are limited. In this study, we compared results from 2DTEE, 3DTEE and MSCT on AV dimensions before and after establishing an interdisciplinary consensus decision on a standardized TAVR imaging protocol and aimed to determine structural predictors for the occurrence of pAR after TAVR with the self-expanding Medtronic CoreValve prosthesis (Medtronic, Minneapolis, MN, USA).

At study initiation, we established an interdisciplinary 3DTAVR imaging protocol with exact definition of a stepwise approach to visualize the anatomical landmarks determining the AV annulus (Fig. 1) (9) and two experienced examiners (MSCT and 3DTEE) were trained on the imaging protocol with simultaneous determination of AV diameters in 10 prospective patients, who did not enter the final study group.

The final study group consisted of 138 consecutive patients undergoing TAVR with the Medtronic CoreValve® prosthesis which were prospectively included and underwent MSCT and 3DTEE. The *clinical efficacy* of TAVR sizing was defined by the occurrence of pAR after 30 days of FU [9]. As proposed by Detaint et al., we calculated the AV cover index (CIx) to estimate the degree of oversizing and to detect potential annulus-prosthesis mismatch [10]. Furthermore, we adapted this formula to calculate cover indices from AV and annular perimeters and areas.

138 consecutive patients (age 81.1 ± 5.9 years) at high surgical risk (logistic EuroSCORE 26.8 ± 16.1%, STS score 9.3 ± 6.4%) underwent TAVR with the self-expanding Medtronic CoreValve prosthesis (Table 1). In 135 subjects the TAVR procedure was completed successfully with a 30-day all cause mortality of 6.5% (Table 2).

We found a significant, but still moderate, correlation between 2DTEE and MSCT for Dmean (0.79, $p < 0.0001$) and 2DTEE was not applicable for the determination of minimal or maximal diameters, AV annulus perimeters, and AV annulus areas.

All measurements from 3DTEE were significantly correlated with MSCT. The correlation between 3D areas and perimeters from 3DTEE and MSCT was higher than for AV annulus diameters as confirmed by statistical testing for differences between measurements (Dmin, $p = 0.001$; Dmax, $p < 0.0001$; Dmean, $p = 0.025$; area, $p = 0.64$; perimeter, $p = 0.14$) (Tables 3 and 4; Fig. 2). In 88% of cases measurements made by 3DTEE, MSCT would have led to an identical valve size selection. Considering MSCT as the gold standard, 3DTEE underestimated in 7% of the patients the AV size and in 5% of the patients, AV dimensions would have been oversized with 3DTEE.

Both imaging modalities (MSCT and 3DTEE) had a good reproducibility and we found no relevant differences between MSCT and 3DTEE, as shown by intra- and inter-class agreement with correlation coefficients >0.8 (Table 5).

More-than-mild pAR [9] was found in 12 patients after TAVR (7.2%) and all AV geometry defining parameters derived from 3D imaging had a better sensitivity to predict the occurrence of pAR after TAVR than the results from 2D imaging (Table 6 and Fig. 3).

The presence of more-than-mild pAR after TAVR was related to a significantly increased all cause mortality after 30 days ($p < 0.0001$; hazard ratio [HR] 22.3, 95% confidence interval [CI] 5.7–83.4), 6 months ($p < 0.0001$; HR 9.5, 95% CI 3.7–24.9), and 12 months of follow-up ($p < 0.0001$; HR 7.2, 95% CI 3.1–17.1) (Fig. 4, Table 7).

Our study was able to demonstrate that 3DTEE is highly comparable to MSCT for the evaluation of AV geometry prior to TAVR. As stated, echocardiography may substitute MSCT in patients, which cannot undergo MSCT, or when MSCT is not applicable.

When TAVR has started in early 2002, 3D echocardiography was not widely available and the aortic annulus was initially sized by 2-dimensional measurements obtained from TTE. However, TTE has been shown to underestimate the annulus size considerably and 2D TEE was not able to overcome these limitations [11,12]. Since 3D imaging with MSCT allows accurate determination of AV annular geometry, it has become the gold standard for TAVR sizing [11–13]. Since MSCT inherits potential drawbacks and is not widely available, a debate is going on whether modern 3D echocardiography may substitute MSCT in selected patient groups [6]. However, at the current time the published data do not allow for clear recommendations on pre-TAVR imaging with 3DTEE [7,14], and up to now MSCT

Abbreviations: 2DTEE, two-dimensional transesophageal echocardiography; 3DTEE, three-dimensional transesophageal echocardiography; AV, aortic valve; CI, confidence interval; CIx, cover index; Dmin, minimal diameter; Dmax, maximal diameter; Dmean, mean diameter; MSCT, multisliced computed tomography; TAVR, transcatheter aortic valve replacement; pAR, paravalvular aortic valve regurgitation.

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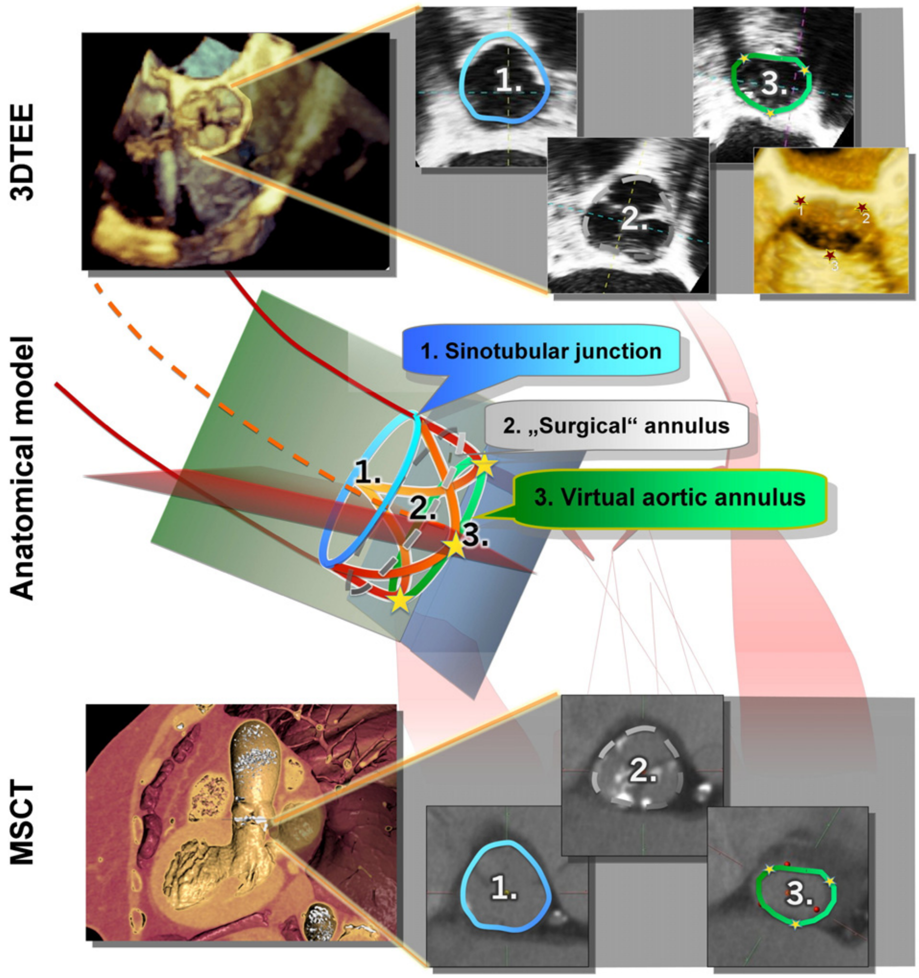

Fig. 1. Model of the aortic root and 3D reconstruction of the anatomical landmarks.TEE, transesophageal echocardiography; MSCT, multisliced computed tomography.Anatomical model of the aortic root and three-dimensional multiplanar reconstruction of the AV annulus from TEE and MSCT with definition/visualization of the [1.] sinutubular junction (blue circle), [2.] the surgical annulus (gray dotted circle), and [3.] the virtual aortic annulus (green circle). For appropriate delineation of the AV annulus the short axis [blue plane] is adjusted to a perpendicular sagittal [green], and a coronal [red] plane and dragged toward the LVOT along a virtual center line [orange dotted line].

Table 1
Baseline characteristics of the study groups.

	All patients (n = 138)
Age (years)	81.1 ± 5.9
Male gender, n (%)	72 (52.2)
Logistic EuroSCORE (%)	26.8 ± 16.1
STS mortality score (%)	9.3 ± 6.4
Coronary artery disease, n (%)	95 (68.8)
Extracardiac arteriopathy, n (%)	61 (44.2)
Previous MI, n (%)	19 (13.8)
Previous PCI, n (%)	53 (38.4)
Previous CABG, n (%)	24 (17.4)
Previous stroke, n (%)	27 (19.5)
Chronic renal failure, n (%)	80 (58.0)
COPD, n (%)	51 (37.0)
Pulmonary hypertension, n (%)	45 (32.6)
Left ventricular EF (%)	50.5 ± 14.8
Pmean (mmHg)	42.7 ± 16.8
AVA (cm^2)	0.7 ± 0.2

STS, society of thoracic surgery; MI, myocardial infarction; PCI, percutaneous coronary intervention; CABG, coronary artery bypass grafting; COPD, chronic obstructive pulmonary disease; EF, ejection fraction; Pmean, mean pressure gradient; AVA, aortic valve area.

Table 2
Procedural details, acute results and outcome data after TAVR.

	All patients (n = 138)
Pre-dilatation, n (%)	62 (44.9)
Access site	
–Trans-femoral, n (%)	131 (94.9)
–Trans-subclavian, n (%)	6 (4.3)
–Trans-aortic, n (%)	1 (0.7)
Procedure time (min)	73.0 (59.0/90.0)
Contrast dye (mL)	180 (132/217)
Post-dilatation, n (%)	48 (34.8)
Acute complications	
Annular rupture	1 (0.7)
Ventricular perforation	1 (0.7)
Valve embolization	1 (0.7)
Valve-in-valve implantation	8 (5.8)
Stroke, n (%)	3 (2.2)
Myocardial infarction, n (%)	2 (1.4)
Major vascular complications, n (%)	8 (5.8)
Pacemaker implantation, n (%)	23 (16.7)
Outcome data	
30-day mortality, n (%)	9 (6.5)
6 months mortality, n (%)	20 (14.5)
12 months mortality, n (%)	29 [15]