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Original article

Superiority of novel automated assessment of aortic annulus by intraoperative three-dimensional transesophageal echocardiography in patients with severe aortic stenosis: Comparison with conventional cross-sectional assessment

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ABSTRACT

Background: Previous studies have demonstrated that three-dimensional (3D) transesophageal echocardiography (TEE) is an alternative to multi-detector computed tomography (MDCT) for aortic valve sizing in transcatheter aortic valve replacement (TAVR). However, conventional cross-sectional analysis of aortic annulus by 3D TEE has some limitations such as lengthy analytical time. A novel software for automated valve measurement has been developed for 3D TEE. We evaluated the accuracy and analytical time of aortic annular measurements using this novel automated software in the clinical setting.

Methods: We retrospectively studied 43 patients with symptomatic severe aortic stenosis (AS) who underwent TAVR. All patients underwent intraoperative TEE and MDCT. We measured aortic annular area by automated, semi-automated, and cross-sectional methods using 3D TEE datasets. These measurements were compared to the corresponding MDCT reference values. We also compared the analytical time of the three methods.

Results: Automated and semi-automated analyses required significantly shorter analytical time compared to cross-sectional analysis (automated: 30.1 ± 5.79 s, semi-automated: 74.1 ± 15.0 s, manual: 81.8 ± 18.5 s, $p < 0.05$). Compared to MDCT measurement (393.7 ± 81.0 mm^2), annular areas measured by automated and cross-sectional methods were significantly smaller (automated: 380.6 ± 77.1 mm^2, cross-sectional: 374.7 ± 76.8 mm^2, $p < 0.05$), while that obtained by semi-automated method was not significantly different (387.7 ± 75.8 mm^2). Annular areas determined by semi-automated and cross-sectional analyses had narrower limits of agreement (LOA) with MDCT measurements, compared to automated analysis (automated: −68.6 to 94.7 mm^2, semi-automated: −48.3 to 60.2 mm^2, cross-sectional: −40.0 to 77.9 mm^2). Measurements by all three methods using 3D TEE showed high correlation with MDCT measurement (automated: $r = 0.86$, semi-automated: $r = 0.94$, cross-sectional: $r = 0.93$).

Conclusions: For aortic annular measurements using 3D TEE in AS patients, semi-automated analysis using the novel automated software reduced analytical time while maintaining similar accuracy compared to the conventional cross-sectional analysis. This automated software may have acceptable feasibility in the clinical setting.

Introduction

Transcatheter aortic valve replacement (TAVR) has been established as a feasible therapeutic alternative for high-risk and intermediate-surgical risk patients with symptomatic severe

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aortic stenosis (AS) [1,2]. Noninvasive cardiac imaging for accurate sizing of the aortic root plays a central role in pre-procedural anatomical evaluation for TAVR [3–6]. Previous studies demonstrated that cross-sectional measurements by multi-detector computed tomography (MDCT) as well as three-dimensional (3D) transesophageal echocardiography (TEE) offer greater discriminatory value for post-TAVR paravalvular aortic regurgitation than two-dimensional (2D) TEE measurement [3,6–8]. On the other hand, cross-sectional measurement of aortic annulus by 3D TEE has some limitations, such as low inter- and intra-observer variabilities [9] and lengthy analytical time. Evaluation of a novel automated software reported superior reproducibility of the data obtained from automated 3D modeling compared to conventional cross-sectional assessment by 3D TEE [10]. However, there is a paucity of data on the accuracy and analytical time of using the novel software for sizing the aortic annulus in severe AS patients before TAVR. The present study aimed to evaluate the accuracy and analytical time of a novel automated software for aortic annulus measurements using 3D TEE data compared with conventional cross-sectional measurement in candidates of TAVR for severe AS.

Methods

Population

We retrospectively studied symptomatic severe AS patients who underwent TAVR between January and October 2016 at Tokyo Bay Urayasu-Ichikawa Medical Center. All patients underwent transthoracic echocardiography (TTE), TEE including 3D TEE, and MDCT. The present study was approved by the human ethics committee at the Tokyo Bay Urayasu-Ichikawa Medical Center. Informed consent regarding participation in the present study was obtained from all subjects.

Echocardiography

TTE was performed using commercially available ultrasound transducer and equipment. Our echocardiography laboratory is operated under the guidelines of the Japanese Society of Echocardiography [11]. Conventional TTE parameters including cardiac dimensions and left ventricular ejection fraction were calculated according to recommended guidelines [12]. Peak transaortic velocity and mean transaortic pressure gradient were derived from transaortic flow recorded by continuous-wave Doppler using a multi-window approach. Aortic valve area (AVA) was calculated according to the continuity equation [13]. Severe AS was defined as peak transaortic velocity $\geq$4 m/s, mean transaortic pressure gradient $\geq$40 mmHg, and AVA < 1.0 cm^{2}according to the 2014 American College of Cardiology/American Heart Association guideline [14]. Low-flow, low-gradient AS patients, defined as indexed stroke volume < 35 mL, mean transaortic pressure gradient < 40 mmHg, and AVA < 1.0 cm^2, underwent stress echocardiography to diagnose true severe AS.

3D TEE was performed using the ACUSON SC2000 PRIME system with Z6Ms volume imaging transducer (Siemens Medical Solutions USA, Inc., Mountain View, CA, USA) just before TAVR. 3D volume was obtained using 3D zoom mode acquired over one cardiac cycle. 3D TEE data of the entire aortic root from the aortic annulus to the sino-tubular junction were acquired for later off-line analysis.

3D TEE was performed by echocardiologists experienced in TAVR imaging (H.W. and K.S.) under optimal sedation by general anesthesia. All 3D TEE measurements were performed by two readers (N.K. and K.S.) blinded to MDCT measurements. Repeated measurements were used for inter-observer variability study, while measurements for intra-observer variability study were done more than one month apart.

Automated software for aortic annulus measurement using 3D TEE data

3D TEE datasets were analyzed off-line on Syngo® SC2000 Workplace with the automated software "eSieValves™" (Siemens Medical Solutions USA, Inc.). The principles of automated modeling of the aortic valve and aortic root using knowledge-based algorithms have been described previously [15,16].

In fully automated analysis, we firstly chose the early systole frame in the 3D TEE dataset as recommended by the American Society of Echocardiography [13]. Next, we confirmed the timing in the 3D TEE dataset for automated analysis of the aortic valve. The following anatomic landmarks were identified automatically: the lowest points of insertion of the three leaflet hinges, the three commissures, the midpoints of the three leaflet tips, and the two coronary ostia, as shown in Fig. 1a. Several seconds later, the software automatically displayed an Excel table with the quantities of various parameters analyzed in the selected frame.

In semi-automated analysis, we modified the delineation of the basal ring manually and obtained the measurements automatically, as shown in Fig. 1b. Several seconds later, the software automatically displayed an Excel table with the quantities of various parameters.

In conventional cross-sectional assessment by 3D TEE, two orthogonal long-axis planes and short-axis planes of the aortic valve were extracted manually from the 3D TEE dataset using multiplanar reconstruction mode, as shown in Fig. 2. After choosing the early-systole frame, we obtained the 2D transverse plane at the level of the aortic annulus, defined as the plane including all lowest cusp hinge points. Then we traced the aortic annulus and consequently measured the aortic annular area and perimeter [17].

Analytical time for measurements was defined as the time from choice of the 3D TEE dataset to display of an Excel table with quantities of various parameters.

MDCT

MDCT imaging was performed as a whole-heart scan on a 320-row MDCT scanner (Toshiba AquilionOne Dynamic Volume CT, Otawara, Japan). The 320-row MDCT was performed by helical scanning with an electrocardiography-gated window. The CT gantry rotation time was 350 ms. The tube voltage was 100 kV and the tube modulation was 300–550 mA for all patients. None of the patients received beta-blockers. The patients received 16.0 mgI/kg/s of iopamidol 300 mgI/ml (Iopamiron-300; Bayer HealthCare, Osaka, Japan) followed by 30 mL of normal saline injected into a superficial vein in the antecubital fossa. Bolus tracking was performed using a 180 Hounsfield unit (HU) threshold in the descending aorta.

The aortic root image was selected at 30% of R–R interval. On a commercially available workstation (Ziostation2 and PhyZiodynamics Technology, Ziosoft Inc., Tokyo, Japan), two orthogonal multi-planar reconstruction planes bisected the long axis of the LVOT in parallel and a transverse plane displayed the short axis of the aortic annular view beneath the lowest insertion points of all three aortic cusps. Area and perimeter of the aortic annulus were measured on the aortic annular plane.

Prosthetic valve sizing for TAVR

Valve sizing for TAVR was decided by the operator using data that provided prospective knowledge of cross-sectional CT