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Added value of cardiac computed tomography for evaluation of mechanical aortic valve: Emphasis on evaluation of pannus with surgical findings as standard reference

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ABSTRACT

Background: The added value of cardiac computed tomography (CT) with transesophageal echocardiography (TEE) for evaluating mechanical aortic valve (AV) dysfunction has not yet been investigated. The purposes of this study were to investigate the added value of cardiac CT for evaluation of mechanical AVs and diagnoses of pannus compared to TEE, with surgical findings of redo-aortic valve replacement (AVR) used as a standard reference.
Methods: 25 patients who underwent redo-AVR due to mechanical AV dysfunction and cardiac CT before redo-AVR were included. The presence of pannus, encroachment ratio by pannus, and limitation of motion (LOM) were evaluated on CT. The diagnostic performance of pannus detection was compared using TEE, CT, and CT + TEE, with surgical findings as a standard reference. The added value of CT for diagnosing the cause of mechanical AV dysfunction was assessed compared to TTE + TEE.
Results: In two patients, CT analysis was not feasible due to severe metallic artifacts. On CT, pannus and LOM were found in 100% (23/23) and 60.9% (14/23). TEE identified pannus in 48.0% of patients (12/25). CT, TEE, and CT + TEE correctly identified pannus with sensitivity of 92.0%, 48.0%, and 92.0%, respectively ($P = 0.002$ for CT vs. TEE). In 11 of 13 cases (84.6%) with inconclusive or negative TEE results for pannus, CT detected the pannus. Among 13 inconclusive cases of TTE + TEE for the cause of mechanical AV dysfunction, CT suggested 6 prosthetic valve obstruction (PVO) by pannus, 4 low-flow low-gradient PVO, and one LOM without significant PVO.
Conclusions: Cardiac CT showed added diagnostic value with TEE in the detection of pannus as the cause of mechanical AV dysfunction.

1. Introduction

Pannus formation after valve replacement is uncommon but can lead to serious complications [1]. With the increasing prevalence of valvular heart disease such as degenerative aortic stenosis or bicuspid aortic valve disease, surgical aortic valve replacement (AVR) with a mechanical valve is commonly performed [2,3]. Although prosthetic mechanical valve function is traditionally evaluated with transthoracic echocardiography (TTE) and cinefluoroscopy, identification of the exact cause of prosthetic valve dysfunction, such as thrombus or pannus, by TTE or cinefluoroscopy is occasionally difficult [4]. Current guidelines recommend performing transesophageal echocardiography (TEE) when prosthetic valve obstruction is suspected on TTE [5–7], however, it is often difficult to detect the cause of prosthetic valve dysfunction or obstruction by TEE, especially for valves in aortic positions [8,9].

Cardiac computed tomography (CT) has become an emerging technique in the evaluation of prosthetic valves, with a complementary role to TTE and TEE. CT can provide information about prosthetic valve motion [10,11] and prosthetic valve obstruction (PVO) [12–14]. A few studies have reported the utility of cardiac CT for detecting pannus formation as a cause of prosthetic valve dysfunction or obstruction in the aortic position [13–18]. Other studies investigated the clinical significance of pannus detected on CT, correlating CT findings of pannus with TTE parameters [19,20]. However, in those studies CT results could not be confirmed due to a lack of standard reference through surgical findings. To our knowledge, the added value of cardiac CT with TEE for evaluating prosthetic aortic valve (AV) dysfunction, especially in

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pannus detection, has not yet been investigated, although TEE is regarded as a useful modality for evaluating prosthetic valves [8,9,21–24].

The purposes of this study were to investigate the added value of cardiac CT for detection of pannus and evaluation of mechanical AV dysfunction compared to TEE, with surgical findings of redo-AVR used as standard reference.

2. Methods

2.1. Patients

Approval was obtained from the Institutional Review Board of our institution, and informed consent was waived for this retrospective study. The study included 33 patients who received redo-AVR due to mechanical AV dysfunction from December 2011 to February 2015 and underwent cardiac CT before redo-surgery. Patients who underwent redo-AVR surgery due to paravalvular leak (n = 2) or who did not undergo TEE before redo-surgery (n = 6) were excluded from the study. The presence of mechanical AV dysfunction and indication for redo-AVR surgery were preoperatively assessed by a combination of TTE, TEE, and CT findings. A total of 25 patients were included in the final analysis. Of 25 patients, 9 were included in a study by Suh et al. [20]. The previous study focused on the correlation of CT finding with TTE parameter and the determination of predictor of clinically significant pannus. However, our study focused on the added value of CT for detection of pannus and evaluation of mechanical AV dysfunction compared to TTE and TEE. Demographic data and information on mechanical valves and surgical techniques were collected from electronic medical records.

2.2. Image acquisition

All CT scans were performed with a dual-source CT scanner (SOMATOM Definition Flash; Siemens Health Care, Forchheim, Germany). Scans were performed with retrospectively electrocardiogram-gated data acquisition using the triple-phase contrast injection method. Image reconstruction was performed with a medium kernel (b36f), and reconstruction slice thickness was 0.75 mm with 0.5 mm increments. For all patients, 10 data sets were reconstructed every 10% of the cardiac cycle. Reconstructed images were transferred to an image server and analyzed using dedicated three-dimensional software (Aquarius iNtuition, Ver 4.4.11, TeraRecon, San Mateo, CA, USA). The scanning parameters were as follows: detector collimation, 64 × 0.6 mm; section acquisition, 128 × 0.6 mm by means of a z-flying focal spot; gantry rotation time, 280 msec; pitch, 0.17–0.38 (adapted to heart rate); tube current-time product, 240–450 mAs; tube voltage, 80–100 kV; and temporal resolution, 75 msec. The mean estimated radiation effective dose was 9.63 mSv.

2.3. Image analysis

All CT analyses were performed by consensus reading of two radiologists who were blinded to clinical information and TTE results. Assessment of a mechanical AV consisted of the presence of pannus or other cause of PVO (thrombus or vegetation), evaluation of leaflet motion and direct planimetry of the geometric orifice area (GOA), and effective orifice area (EOA) of the mechanical AV. The presence of subprosthetic soft tissue mass with low-attenuation (pannus) was assessed. If a pannus was present, the location was analyzed. Pannus location was classified as focal or circumferential involvement, and focal involvement was subclassified according to a localization system based on the surgical view [12,25]. A short-axis view of the mechanical AV was used to measure the GOA and EOA by planimetry of the prosthetic valve and subprosthetic area (internal edge of pannus if a pannus was present) on systolic phase, as described in a previous study [19]. The encroachment ratio (as a percentage) was defined using the following equation: [(GOA − EOA) / GOA · 100] [19]. Opening and closing angles (angle between the leaflet and orifice ring) were measured in the fully open and closed positions [11]. When CT attenuation of a subvalvular mass was lower than that of the interventricular septum, thrombus was favored over pannus [14]. Vegetation was defined as irregularly shaped masses adherent to the prosthetic valve ring or leaflets [26]. Limitation of motion (LOM) of a mechanical AV was considered present when motion of a leaflet or leaflets was restricted, with an opening angle decreased more than 4° compared to the manufacturer's value [18]. The On-X valve was an exception, with a LOM present if the opening angle was decreased more than 11° than the manufacturer's value [27].

2.4. TTE and TEE technique and evaluation

TTE studies were performed with commercially available echocardiography equipment (SC2000, Siemens Healthcare; or iE33, Philips Healthcare; or Vivid7, E9, GE Healthcare). Transvalvular PG and left ventricular ejection fraction were assessed. Elevated transvalvular PG was defined as a mean PG equal to or greater than 40 mm Hg [7]. Patients underwent TEE examination with a Philips iE33 ultrasound system and an X7-2t transesophageal transducer (Philips Medical Systems, Andover, MA, USA). The presence of subprosthetic pannus and other causes of PVO (thrombus or vegetation) were assessed by combination of 2-dimensional and 3-dimensional TEE findings. When a subvalvular mass was visible, distinction between thrombus and pannus was identified by clinical characteristics (duration of symptoms, anticoagulation status) and by echocardiographic parameters. Thrombus was more suggested in cases of large mass with soft echodensity, and pannus was more suggested in cases of small echodense mass [24,28]. Vegetation was defined as irregularly shaped oscillating or non-oscillating masses adherent to and distinct from the myocardium [29]. TEE results were considered inconclusive when the presence of subprosthetic masses was not assessable due to shadowing from mechanical AVs or co-existing mechanical mitral valves.

2.5. Fluoroscopy technique and evaluation

Cinefluoroscopy images were obtained with multiple fluoroscopy units (biplane or single plane). Opening angles were measured using the plane of the annulus as the baseline. LOM was considered present when the motion of a leaflet or leaflets was restricted, with an opening angle smaller than the mean value +2 standard deviations obtained in a reference group of patients with normally functioning valves of the same type [30].

2.6. Cause of mechanical AV dysfunction

The cause of mechanical AV dysfunction was assessed based on TTE + TEE and based on combining CT results with TTE + TEE. Mechanical AVs were classified for valves with PG elevation (transvalvular PG ≥ 40 mm Hg) and valves with normal PG (transvalvular PG < 40 mm Hg). Valves with PG elevation were subclassified as PVO by thrombus, PVO by pannus, and patient-prosthesis mismatch (PPM). On TTE + TEE, the cause of mechanical AV dysfunction was defined as following [28]. PPM was suggested when all of the following criteria were met: (1) indexed EOA (EOA/body surface area (BSA)) <0.85 cm^2/m^2, (2) high baseline post-operative PG, and (3) no LOM or subvalvular mass seen on TEE and/or fluoroscopy [7,9]. On TTE + TEE, PVO by thrombus or pannus was suggested when all of the following criteria were met: (1) increased PG observed compared to postoperative baseline TTE, (2) EOA < 0.8 cm^2, and (3) subvalvular mass seen on TTE [7]. PVO by thrombus was suggested when all of the following criteria were met: (1) LOM present on TEE or fluoroscopy, or (2) large subvalvular mass seen on TEE. PVO by pannus was defined when one