The most common causes of mechanical prosthetic valve dysfunction (PVD) are thrombosis and pannus overgrowth. Transthoracic echocardiography (TTE), transesophageal echocardiography (TEE), and fluoroscopy are commonly used in the evaluation of prosthetic heart valves. However, none of these imaging techniques provides an accurate diagnosis of pannus overgrowth without surgical confirmation. See Editorial by Bonnichsen and Pellikka.

We have recently reported that thrombolytic therapy (TT) should be considered as a first-line treatment in patients with prosthetic valve thrombosis unless contraindicated. Two-dimensional and real-time 3-dimensional TEE accurately identify prosthetic valve thrombosis with good sensitivity. However, the inability to definitively diagnose pannus is a major drawback of conventional imaging methods, though real-time 3-dimensional TEE may have some value. Pannus has been reported to accompany thrombus in almost half of the cases with prosthetic valve obstruction, whereas it has been reported to occur in isolation in one fifth of cases. It has also been typically found to be a major reason for failed thrombolysis in prosthetic valve thrombosis. Over the past 5 years, a few case reports and research studies with limited number of patients have been published regarding the use of multidetector computed tomography (MDCT) for the

Background—Distinguishing pannus and thrombus in patients with prosthetic valve dysfunction is essential for the selection of proper treatment. We have investigated the utility of 64-slice multidetector computed tomography (MDCT) in distinguishing between pannus and thrombus, the latter amenable to thrombolysis.

Methods and Results—Sixty-two (23 men, mean age 44±14 years) patients with suspected mechanical prosthetic valve dysfunction assessed by transesophageal echocardiography were included in this prospective observational trial. Subsequently, MDCT was performed before any treatment was started. Periprosthetic masses were detected by MDCT in 46 patients, and their attenuation values were measured as Hounsfield Units (HU). Patients underwent thrombolysis unless contraindicated, and those with a contraindication or failed thrombolysis underwent surgery. A mass which was completely lysed or surgically detected as a clot was classified as thrombus, whereas a mass which was surgically detected as tissue overgrowth was classified as pannus. A definitive diagnosis could be achieved in 37 patients with 39 MDCT masses (22 thrombus and 17 pannus). The mean attenuation value of 22 thrombotic masses was significantly lower than that in 17 pannus (87±59 versus 322±122; P<0.001). Area under the receiver operating characteristic curve was 0.96 (95% confidence interval: 0.91–0.99; P<0.001), and a cutoff point of HU≥145 provided high sensitivity (87.5%) and specificity (95.5%) in discriminating pannus from thrombus. Complete lysis was more common for masses with HU<90 compared with those with HU 90 to 145 (100% versus 42.1%; P=0.007).

Conclusions—Sixty-four slice MDCT is helpful in identifying masses amenable to thrombolysis in patients with prosthetic valve dysfunction. A high (HU≥145) attenuation suggests pannus overgrowth, whereas a lower value is associated with thrombus formation. A higher attenuation (HU>90) is associated with reduced lysis rates. (Circ Cardiovasc Imaging. 2015;8:003246. DOI: 10.1161/CIRCIMAGING.115.003246.)

Key Words: multidetector computed tomography prosthetic heart valves sensitivity and specificity thrombosis transesophageal echocardiography

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Circ Cardiovasc Imaging is available at http://circimaging.ahajournals.org DOI: 10.1161/CIRCIMAGING.115.003246

Valvular Heart Disease

Sixty-Four–Section Cardiac Computed Tomography in Mechanical Prosthetic Heart Valve Dysfunction

Thrombus or Pannus

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imaging of prosthetic heart valves. However, there is still limited information for diagnosing pannus versus thrombus by using MDCT.

Methods

Rationale of the Study Design

Pannus is excessive overgrowth of fibroblastic tissue together with inflammatory cells and interspersed capillary vessels, whereas thrombus is a fibrin mass in which erythrocytes, platelets, and leukocytes are enmeshed.²⁹,³⁰ Based on the histopathologic differences between pannus and thrombus, we hypothesized that the value of x-ray attenuation of pannus may differ from that of thrombus. Before starting patient enrollment, we tested 3 patients with obstructive PVD (Figure 1A) who were scheduled for valve replacement surgery. They were imaged with MDCT, and periprosthetic masses with high attenuation were detected (Figure 1B). Pannus overgrowth was proved surgically in all patients (Figure 1C). Postoperatively, the excised valves were also imaged with MDCT, and pannus was clearly visualized (Figure 1D). In addition, 2 patients with prosthetic valve thrombosis underwent MDCT before and after successful TT. Pre-thrombolysis MDCT revealed masses with low attenuation consistent with thrombus (Figure 2A), whereas post-thrombolysis scans showed disappearance of the masses (Figure 2B). The observation that pannus had higher attenuation values than thrombus served as the basis for this prospective study.

Patient Population and Study Design

Overall 62 patients (23 men, mean age 44±14 years) with suspected PVD were included in the study between 2007 and 2014. All patients were initially evaluated with TTE and TEE and subsequently with 64-section MDCT before any treatment was started. Tomographic images were examined to visualize periprosthetic masses. The attenuation values of the masses were measured as Hounsfield Units (HU). Patients with a positive TEE result (thrombus and suspected pannus) underwent TT unless contraindicated.⁵ Those with a contraindication to TT or failed TT underwent surgery. Thrombolysis was also performed in patients with negative TEE results (no mass visualized) but proven restricted valve mobility on fluoroscopy. If TEE was negative and fluoroscopy was normal, a possible diagnosis of patient prosthesis mismatch was made, and surgery was considered in symptomatic patients. We used the following predefined reference criteria as the gold standard for a definitive diagnosis.

Surgery

Macroscopic and microscopic histopathologic examination of the excised material was considered as sufficient evidence for a definitive diagnosis of thrombus and pannus.

Complete Thrombolysis

Complete disappearance of the mass with restoration of valve function in patients with obstructive or nonobstructive PVD who underwent TT was considered sufficient evidence for a definitive diagnosis of thrombus.

Figure 1. Despite elevated gradients and decreased valve area (A), the cause of obstruction could not be determined with transesophageal echocardiography (TEE) in a patient with prosthetic valve dysfunction (PVD; ATS bileaflet valve). Multidetector computed tomography (MDCT) revealed a periprosthetic mass (B) with markedly high attenuation (HU: 420) which smears the internal surface of the valve ring and narrows the inflow of mechanical valve. The patient underwent operation, and excessive pannus overgrowth was present (C). Volume rendering demonstration of pannus over the removed prosthetic valve (D). HU indicates Hounsfield unit.
Partial lysis (any decrease in thrombus burden as assessed by TEE) was not considered to provide a definitive diagnosis of thrombus. However, TT was considered successful when there was a ≥50% decrease in thrombus burden with a final thrombus diameter <10 mm along with a decrease in valve gradient and increase in valve area and symptomatic improvement. All patients with residual nonobstructive thrombi after TT were followed-up with intensified anticoagulation.

The study was approved by the Local Ethics Board, and informed consent was obtained from all patients. The exclusion criteria were infective endocarditis, elevated serum creatinine level (>1.5 mg/dL in men and >1.2 mg/dL in women), history of iodine contrast agent allergy, pregnancy, hyperthyroidism, bronchial asthma, and inability to lie supine or breath-hold because of pulmonary congestion. The baseline characteristics, such as age, sex, elapsed time since valve surgery, type and brand of the valve, thrombus site, functional capacity, anticoagulation status, heart rhythm, and echocardiographic findings were stored in a database.

Echocardiography
TEE was performed using a 3 MHz transducer while the patients were at rest in the left lateral decubitus position. TEE was performed using the Vivid 3 and 7 systems (General Electric, Milwaukee, WI) with a 5 MHz multiplane probe during the first 2 years and with a real-time 3-dimensional TEE (Philips x7–2t IE33, Andover, MA) during the last 5 years. A thrombus was defined as per earlier studies.4,5 The criteria for PVD were a valve area ≤1.7 cm² and transprosthetic mean gradient ≥10 mmHg for mitral or tricuspid mechanical valves; an effective orifice area ≤0.8 cm² or transprosthetic mean gradient ≥40 mmHg and a dimensionless index <0.25 for aortic mechanical prostheses; and a nonobstructive thrombus ≥10 mm for any valve. TTE and TEE imaging were performed and interpreted by 2 experienced cardiologists; and all diagnoses were made by consensus. The outcomes of TT were evaluated with TEE in all patients.

MDCT: Data Acquisition
Imaging was performed using a 64-slice MDCT scanner (Philips Brilliance CT 64-channel scanner, USA) with retrospective electrocardiographic gating. Image acquisition was performed during a single 10-s end-inspiratory breath-hold. Scan parameters included 0.4 s gantry rotation time, a slice collimation of 64×0.625 mm, fixed tube voltage of 120 mV, and median tube current of 600 mAs (range 500–800 mAs). The scans were performed when the patients were asymptomatic (absence of dyspnea, tachypnea, or orthopnea; all of which are symptoms of pulmonary congestion), in a fasting state, and in the supine position. Eighty milliliters of contrast material (400 mg iodine/mL) at a rate of ≈5 mL/s and subsequently 50 mL saline solution at a rate of 5 mL/s were infused using an intravenous automated injection system to visualize mechanical valves more clearly and to better delineate the masses on the valves. The scans were triggered automatically when the predefined contrast intensity in the descending aorta was achieved. The locator was adjusted to have the lowest possible size which was sufficient to evaluate only the mechanical prosthetic valve to reduce the radiation exposure. The pitch value was 0.2. After obtaining the raw data, excessive irregularities in the RR interval (because of atrial fibrillation or isolated extrasystoles, etc) were eliminated. Reconstruction was automatically obtained in 40% and 75% of the RR interval, and additional reconstructions were obtained with a 20% increase between 0% and 80% routinely and with smaller increments when necessary. The reconstruction phase which had the highest image quality in which the valve created minimum artifact was used for the analysis. Patients with atrial fibrillation were pretreated with either metoprolol, verapamil, digoxin, and amiodarone or a combination of these drugs either orally or intravenously for several days (1–4 days) before MDCT scanning. If the heart rate was still ≥65 bpm immediately before scanning, intravenous esmolol in patients who could tolerate it was used as previously described31 in patients with either sinus rhythm or atrial fibrillation.

MDCT: Image Analysis
The MDCT images were analyzed in special processing units (Philips Extended Brilliance Workspace; Philips Medical Systems). The original axial images were examined with oblique and curved multiplanar reformations, maximum intensity of projection, and volume rendering reconstructions. All images were analyzed by 2 radiologists with >10 years of experience who were blinded to clinical data. The MDCT scans were initially divided as diagnostic and nondiagnostic. A diagnostic image was defined as the image in which the valve and the mass were clearly visible in at least one reconstruction phase free of artifacts. Moreover the diagnostic images were further divided into 2 categories, including moderate images and good images. Those with optimal scan quality in ≥2 phases were considered good, whereas scans with only one optimal reconstruction phase were considered to be moderate.

Multiplanar reconstruction was used for choosing the optimal plane, either orthogonal or oblique, in which the mass was visualized with the least metallic artifact, and HU measurement was least interfered with by artifact. A small circular region of interest with a size adapted to the individual mass was correctly placed within the mass. The region of interest was never placed beneath the metallic rim or to the rim of the mass to avoid the partial volume effect. Low attenuation artifacts beneath the prostheses may be seen as false-positive masses, but cannot be followed throughout the cardiac cycle and, hence, were excluded. In addition, metallic blooming artifacts may also be seen as false-positive high attenuation masses and, hence, were readily recognized and excluded (Figure 3). The HU measurements were repeated for several times to assess the influence of possible artifacts, and when consistent measurements were obtained from 3 different points, the average of 3 measurements was noted as the exact HU of the mass.

Statistics
Statistical analysis was performed with SPSS 19.0. The variables were investigated with the use of the Shapiro–Wilk test to determine...
months. The baseline characteristics are shown in Table 1.

Echocardiographic and Fluoroscopic Results

PVD determined by TTE and TEE was found in all patients. Accordingly, obstructive PVD was present in 42 (67.6%) patients and nonobstructive PVD in 20 (32.4%) patients. TEE was positive in 54 (87.1%) patients. Among these, 35 (56.5%) had thrombus, 13 (21%) had suspected pannus, 6 (9.7%) had suspected pannus with superimposed thrombus. However, TEE was negative in 8 (12.9%) patients, despite obstructive PVD. The 8 TEE-negative patients underwent fluoroscopy, and 3 of them had limited valve excursion and the remaining 5 showed normal fluoroscopic findings.

The means of thrombus and valve areas, along with maximum and mean gradients for obstructive and nonobstructive PVD subgroups, are presented in Table 2.

Results of TT and Surgery

Only 46 of 54 TEE-positive patients underwent TT, and the overall success rate was 72% (33 patients). The mean tissue-type plasminogen activator dose used was 66±35 mg per TT episode. Of 33 patients with successful TT, 21 had complete lysis, and hence, their masses were considered as thrombus.

Overall, 22 patients underwent surgery. These included 8 patients with TT contraindications, 2 patients with patient-prosthesis mismatch, and 12 patients with failed TT or partial thrombolysis. Postoperative histopathology of excised materials determined the definitive diagnosis. There were 3 cases without a mass on the excised valve (2 with patient-prosthesis mismatch and 1 with suture entrapment), 2 cases with isolated thrombus, 2 with pannus and superimposed thrombus, and 15 with isolated pannus. Hence, 17 masses were considered as pannus and 4 masses as thrombus.

The histopathology of pannus revealed dense fibrosis (hyalinized collagen) along with myofibroblasts, chronic

Results

Baseline Characteristics

Although a total of 66 patients with PVD were initially enrolled, only 62 patients, including 39 females and 23 males, with a mean age of 44±14 years were included in the study. The remaining 4 patients were excluded because of persisting symptoms of pulmonary congestion, which did not allow MDCT imaging before starting any treatment. A subtherapeutic international normalized ratio was present in 32 (51.6%) patients on admission. The prevalence of poor functional capacity (New York Heart Association class IV) was quite low (4.8%). The rhythm was atrial fibrillation in 20 patients (32.3%). The most common valve type was a St Jude bileaflet valve in 40.3% of the patients, with the mitral position being the most common thrombus site (51 [82.3%] patients). The median elapsed time since valve surgery was 75 (range 3–324) months. The baseline characteristics are shown in Table 1.

Figure 3. A-F. The streaking artifacts (black arrows) in different RR intervals in a patient with prosthetic valve leaflet blockage caused by thrombus formation are demonstrated. Note that the fewest artifacts are in 75% (E) and 80% (F) RR intervals. Beam hardening artifact (white arrows) beneath the prosthetic ring interferes with the HU measurement of the thrombus located at the same location in 0% to 60% RR intervals (A–D). Note the absence of beam hardening in the same location and clear visualization of thrombus free of artifact which allows exact HU measurement (E and F). Blooming artifact seen as a bright shadowing with a smooth surface which might be mistaken as a high attenuation (HU 550) mass (black arrows) near the metallic ring is readily recognized and was excluded (G and H). A true high-attenuation mass (white arrows) with an irregular surface circumferentially smearing the prosthetic rings is seen. This was proven to be pannus surgically (I and J). Thrombotic masses located at the atrial (white arrow) and ventricular (black arrows) sides of the prosthetic ring are obvious (K). Note the extremely dark area (arrow head) caused by beam hardening of the metallic prosthesis which might be mistaken as a low attenuation mass (K). See the small region of interest placed as far from the prosthesis as possible and adapted to the thrombus shape revealing an HU of 54 (L).
new international normalized ratio; ML, monoleaflet; NYHA, New York Heart Association; PVD, prosthetic valve dysfunction.

*Plus–minus values are means±SD.

inflammatory cells, and endothelial cells in all cases. Calcification was present in 13 (76.4%) and capillary vessels in 16 (94.1%) cases. The histopathologic data are summarized in Table 3.

MDCT Scan Quality and Predictors of High-Quality Scans During MDCT scans, the median heart rate was 59 bpm (range 49–68). The dose of the radiation given to the patient was 8.5±1.9 mSv depending on the heart rate. Overall, 58 patients had diagnostic images, and among them, 52 (89.6%) patients had good images and 6 (10.4%) had moderate images. In 12 of 58 patients with sufficient image quality, no periprosthetic mass could be demonstrated (MDCT negative). These 12 patients had diagnostic images, and among them, 52 (89.6%) had good images, and 6 (10.4%) had moderate images. Among masses with HU<145, receiver operating characteristic analysis (Figure 7) revealed a cutoff point of HU≥145 (sensitivity 87.5%, specificity 95.5%, area under the curve 0.96 [95% CI: 0.91–1; P<0.001]) that discriminated pannus from thrombus.

There were 22 patients having 31 masses with HU<145, of whom 20 underwent TT. Of these, 16 had complete lysis, 3 had partial lysis, and 1 had failed TT (95% TT success rate). Among masses with HU<145, receiver operating characteristic analysis yielded a cut point of HU≥90 (area under curve 0.96, 95% CI: 0.87–1, sensitivity 81%, specificity 100%).

MDCT Characteristics of Periprosthetic Masses Overall, 56 periprosthetic masses were detected by MDCT in 46 patients (1 mass in 38 patients, 2 masses in 6 patients, and 3 masses in 2 patients). The mean attenuation value of these masses was 181±139 HU (range 25–550).

The number of patients undergoing TEE, MDCT, TT, and surgery and those with definitive or undetermined diagnoses are summarized in Table 4. The etiologies of those with definitive diagnoses are shown in Figure 5.

Of the 62 patients with PVD who underwent MDCT imaging, 4 had unusable MDCT images (Figure 6), leaving 58 patients with diagnostic images. MDCT revealed 39 periprosthetic masses in 37 patients with a definitive diagnosis (22 thrombus in Group I and 17 pannus in Group II). The mean attenuation value of these masses was 181±139 HU (range 25–550).

There were only 8 patients with aortic mechanical valves. There were only 8 patients with aortic mechanical valves. Among the 6 patients with aortic mechanical valves, including the 3 nondiagnostic Bjork–Shiley monoleaflet valves, four of the remaining 5 patients with biface leaflet valves were best imaged in 75% or 80% of RR interval. The reliability analysis for the measurements of HU values of periprosthetic masses by MDCT revealed high intraobserver (intraclass correlation coefficient 0.92, 95% confidence interval [CI] 0.87–0.95; P<0.001) consistency. The Bland–Altman analysis revealed a mean HU difference of 15.75±7.02 between the 2 observers with a 95% limits of agreement from −12.18 to 15.08 (Figure 4).
for predicting complete lysis. Complete lysis rate was significantly higher for masses with HU<90, compared with masses with HU of 90 to 145 (100% versus 42.1%; P=0.007). Overall, 3 patients with a mass with HU<145 underwent surgery (including 1 with partial lysis and 2 with no TT). Of these, 2 had thrombus and 1 had pannus.

There were 24 patients having 25 masses with HU>145. Of them, 18 patients initially underwent TT. Of these, 12 had failed thrombolysis, 5 had partial lysis, and 1 had complete lysis (33.3% TT success rate). Overall, 17 patients with a mass with HU≥145 underwent surgery (including 8 with failed TT, 3 with partial lysis, and 6 with no TT). Of these, 14 had pannus, 2 had coexistent pannus and thrombus, and 1 had suture entrapment.

### Diagnostic Performance of MDCT

Per patient analysis revealed 89% (95% CI: 0.74–0.96) sensitivity, 50% (95% CI: 0.03–0.97) specificity, 97% (95% CI: 0.83–0.99) positive predictive value, 20% (95% CI: 0.01–0.70) negative predictive value, and 87% (95% CI: 0.72–0.95) diagnostic accuracy for diagnosing thrombus or pannus with MDCT in patients with PVD.

### Discussion

This study suggests that MDCT is a useful method for the differential diagnosis of masses amenable to TT in patients with PVD. High attenuation (HU≥145) periprosthetic masses are resistant to TT and predict pannus, whereas the low attenuation periprosthetic masses are susceptible to TT and predict thrombus.

Barbetseas et al reported that pannus had a higher video intensity (echogenicity) compared with thrombus.32 However, no data supporting this argument was reported in any subsequent research. The first report regarding the MDCT attenuation of pannus overgrowth revealed that pannus overgrowth in the aortic position appeared as soft tissue with low attenuation (similar to the interventricular septum) in the subprosthetic region.20 On the other hand, our group has reported contrary findings.33,34 Likewise, Ueda et al have recently reported that pannus had markedly higher attenuation compared with the septum.28 The findings in the current study support our previous argument regarding high attenuation of pannus formation. Higher attenuation values of pannus compared with thrombus may be secondary to (1) dense connective tissue and fibrocellular overgrowth that may cause higher absorption of x-rays;

Table 3. Histopathologic Findings of Patients Undergoing Surgery

<table>
<thead>
<tr>
<th>Patient No (n=22)</th>
<th>Age y</th>
<th>Sex</th>
<th>PV Brand-Type-Site</th>
<th>HU</th>
<th>Histopathology</th>
<th>Contents of Pannus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1§</td>
<td>43</td>
<td>F</td>
<td>CM-BL-Mi</td>
<td>248</td>
<td>+</td>
<td>Fibrosis</td>
</tr>
<tr>
<td>2§</td>
<td>37</td>
<td>F</td>
<td>SJ-BL-Mi</td>
<td>445</td>
<td>+</td>
<td>Calcification</td>
</tr>
<tr>
<td>3</td>
<td>19</td>
<td>M</td>
<td>??-BL-Mi</td>
<td>284</td>
<td>+</td>
<td>Vessel†</td>
</tr>
<tr>
<td>4</td>
<td>19</td>
<td>F</td>
<td>SJ-BL-Mi</td>
<td>356</td>
<td>+</td>
<td>Cellularity‡</td>
</tr>
<tr>
<td>5</td>
<td>17</td>
<td>F</td>
<td>SJ-BL-Mi</td>
<td>550</td>
<td>+</td>
<td>Thrombus</td>
</tr>
<tr>
<td>6</td>
<td>58</td>
<td>F</td>
<td>MH-ML-Mi</td>
<td>120</td>
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<td>F</td>
<td>SJ-BL-Mi</td>
<td>170</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>63</td>
<td>F</td>
<td>SJ-BL-Mi</td>
<td>249</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>60</td>
<td>M</td>
<td>MH-ML-Mi</td>
<td>471</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>23</td>
<td>F</td>
<td>So-BL-Mi</td>
<td>310</td>
<td>+</td>
<td></td>
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<tr>
<td>11</td>
<td>43</td>
<td>F</td>
<td>??-BL-Mi</td>
<td>270</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>18</td>
<td>F</td>
<td>??-BL-Mi</td>
<td>279</td>
<td>+</td>
<td></td>
</tr>
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<td>54</td>
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<td>SJ-BL-Mi</td>
<td>416</td>
<td>+</td>
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<td>14</td>
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<td>UC-ML-Mi</td>
<td>190</td>
<td>+</td>
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<td>29</td>
<td>F</td>
<td>OC-ML-Mi</td>
<td>354</td>
<td>+</td>
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</tr>
<tr>
<td>18</td>
<td>61</td>
<td>F</td>
<td>??-BL-Mi</td>
<td>76</td>
<td>+</td>
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<td>19</td>
<td>31</td>
<td>M</td>
<td>CM-BL-Mi</td>
<td>90</td>
<td>+</td>
<td></td>
</tr>
</tbody>
</table>

CM indicates carbomedics; HU, Hounsfield Unit; MH, Medtronic Hall; Mi, mitral; OC, Omnicarbon; PV, prosthetic valve; SJ, St Jude; So, Sorin; and UC, Ultracor.

?? indicates unknown prosthesis brand.

*Fibrosis includes presence of hyalinized dense collagen as extrazellular matrix.

†Visible red blood cells within the capillary lumen and CD34+ endothelial cells lying down the lumen.

‡Lymphocytes, macrophages, and foreign body giant cells, and myofibroblasts.

§This patient had 2 masses and the HU and histopathologic data is shown in the upper row for pannus and in the lower row for thrombus.
(2) the contrast material used in 64-section MDCT scans that may contribute to the enhancement of dense tissue by entering into the pannus via the capillary structures; (3) the fact that the pannus may contain some calcification. It is known that HU values may reach up to 1000 in the presence of calcification. Overall, 12 patients had periprosthetic masses with HU values above 300 in our study.

Current guidelines recommend surgery over TT in patients with prosthetic valve thrombosis. However, we have recently reported that low dose and slow infusion of tissue plasminogen activator provide safe thrombolysis without compromising effectiveness and should be selected as a first-line treatment approach. However, discrimination of pannus and thrombus and predicting the outcome of TT is crucial before starting any treatment, and TTE and TEE may not suffice in this regard. The current study demonstrates the utility of MDCT in selecting the proper treatment and predicting the outcome of TT. The principal cutoff point was found to be a HU≥145 to be used clinically in patients with PVD and a visible mass on MDCT. This cutoff point may discriminate between thrombus and pannus, which is the first step for selecting the proper treatment strategy and is the major drawback of TTE and TEE for such a decision. Those with a HU≥145 most likely will benefit from surgery. The second cut point (HU<90) is derived to guide the second step of the treatment strategy for masses with HU<145, which are most likely considered as thrombus. The second cutoff may predict the outcome of TT. Once thrombus is visualized, those with a HU<90 seem to be completely lysable. Complete lysis is unlikely in masses between 90 and 145 HU. However, there is still a chance of partial lysis that may provide improvement in valve gradients, and hence, referral to surgery may become necessary.

Table 4. Number of Patients With Definitive or Uncertain Diagnoses*

<table>
<thead>
<tr>
<th>Patients (n=62)</th>
<th>TEE (TT, surgery)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mass positive</td>
</tr>
<tr>
<td>MDCT</td>
<td></td>
</tr>
<tr>
<td>Diagnostic image</td>
<td>53 (45, 20)</td>
</tr>
<tr>
<td>Mass (+)</td>
<td>46 (38, 20)</td>
</tr>
<tr>
<td>Definitive diagnosis</td>
<td>37 (29, 20)</td>
</tr>
<tr>
<td>Uncertain diagnosis</td>
<td>9 (9, 0)</td>
</tr>
<tr>
<td>Mass (-)</td>
<td>7 (7, 0)</td>
</tr>
<tr>
<td>Definitive diagnosis</td>
<td>4 (4, 0)</td>
</tr>
<tr>
<td>Uncertain diagnosis</td>
<td>3 (3, 0)</td>
</tr>
<tr>
<td>Nondiagnostic image</td>
<td>1 (1, 0)</td>
</tr>
<tr>
<td>Definitive diagnosis</td>
<td>0 (0, 0)</td>
</tr>
<tr>
<td>Uncertain diagnosis</td>
<td>1 (1, 0)</td>
</tr>
<tr>
<td>Total</td>
<td>54 (46, 20)</td>
</tr>
</tbody>
</table>

MDCT indicates multidetector computed tomography; TEE, transesophageal echocardiography, and TT, thrombolytic therapy.

*The first and second numbers in the parentheses indicate the number of patients undergoing TT and surgery, respectively.
unnecessary. So, for masses with intermediate attenuation (HU=90–145), TT as first-line and referral to surgery if TT fails seems a reasonable strategy. When ≥2 masses with one being HU<145 and another ≥145 coexist, the treatment strategy should be individualized.

In this study, the image quality of monoleaflet mechanical prosthetic valves with MDCT examination was lower (Figure 6A–6C) than bileaflet valves. Similarly, Konen et al also proposed that monoleaflet valves could not be visualized on MDCT.21 However, Symersky et al proposed that the categorical image quality of monoleaflet valves was not bad, and intensive artifact was observed only in Bjork–Shiley and Sorin monoleaflet valves because of the chromium–cobalt compound of the ring; the image quality of the monoleaflet valves of other brands was not as bad because of a carbon–titanium compound ring.25 In the current study, although Sorin and Bjork–Siley valves caused excessive artifacts, Medtronic Hall, Omnicarbon, and Ultracor valves yielded somewhat better images. No artifact was observed when MDCT was performed on excised monoleaflet valves (Medtronic, Ultracor, Omnicarbon) in an artificial setting (Figure 6D). Artifacts emanating from the metallic prostheses and cardiac motion may be a concern in MDCT imaging of mechanical valves. Nevertheless, adequate patient preparation (improving symptoms by medications to make the patient lie supine and breath comfortably, breath-hold exercises, strict heart rate control) on the days preceding electrocardiographically gated MDCT imaging and further heart rate control immediately before the scan are mandatory for achieving good images. Moreover, using an appropriate amount of contrast injected automatically and triggering shooting when opacification of left heart is maximum are also essential. Reducing the field of view to the smallest possible size during data acquisition, using dedicated soft-ware to eliminate excessive RR cycle irregularities, narrow RR interval reconstruction when necessary, and using a small region of interest along with paying special attention to not record artifacts erroneously as masses were other key components of providing accurate measurement of the HU values of periprosthetic masses in the current study. We think that implementation of these steps is essential to obtain satisfactory images and replicate our findings. The data regarding the optimal phases for mitral and aortic valves are compatible with the previous observation that the mid-diastolic RR intervals provide best image quality with low heart rates in patients undergoing MDCT angiography, and none of the patients in the current study was scanned with high (>70) heart rates. Nevertheless, the optimal RR interval may differ in those with faster heart rates, and 40% (end systole), as well as other intervals, should be obtained to assess images free of artifacts to permit accurate HU measurements. It is recognized that the number of patients imaged is relatively low to draw a conclusion for aortic valves, although they were also best imaged at 75% to 80% of the RR cycle.

The diagnostic performance of MDCT in discriminating pannus from thrombus by using the threshold value of HU≥145 has substantial accuracy. However, it should be kept in mind that TEE is still the most reliable method in the diagnosis of thrombus. If there is a suspicion of pannus on TEE, using MDCT as a complementary imaging method for a definitive diagnosis may be a reasonable approach.

Limitations of the Study
One of the major limitations in the current study is that there was a relatively high proportion of patients with atrial fibrillation which could affect the scan quality. However a heart rate <65 bpm was obtained in all patients. A low heart rate has provided a prolonged motion-free time in the cardiac cycle, which ultimately allowed for less blurred images. Furthermore, decreasing the heart rate probably provided some amount of reduction in heart rate variability, which may have contributed to lessening of the effect of the arrhythmia on image quality.
Our patient population was relatively young because rheumatic heart diseases constitute the main cause of prosthetic valve replacement in our country. Exposure to radiation in these patients should not be ignored. Modulation of radiation dose could not be done in our study because the scans were performed by retrospective electrocardiographic gating and the reconstruction interval was increased with 20% increments. However, we attempted to reduce the exposure.
dose using the lowest possible field of interest. Exposure to radiation could have been reduced further if 256/320-channel MDCT would have been used. Dual-source MDCT has high temporal resolution that allows coronary MDCT angiography at higher heart rates and even in the presence of atrial fibrillation. Similarly, it may allow more precise visualization of prosthetic valves and the periprosthetic masses as well. Nevertheless, the image quality is still heart rate–dependent even with dual source MDCT. The ability to decrease radiation dose while maintaining good image quality may render 256/320-detector-row MDCT clinically useful in patients with prostheses. Detection of more periprosthetic masses with such a scanner might be expected but needs further investigation.

Conclusions

The most important findings of this study are as follows: (1) 64-slice MDCT efficiently provides reliable and quantitative data for the diagnosis and differentiation of pannus and thrombus in patients with PVD. X-Ray attenuation of pannus is markedly higher than that of thrombus. If the HU value of the periprosthetic mass is ≥145, pannus can be diagnosed with a high probability. A diagnosis of thrombus is likely when periprosthetic masses with lower attenuation are present. (2) MDCT can also predict the response to TT in prosthetic valve thrombosis. Complete lysis can be obtained with TT in almost all periprosthetic masses with a HU value <90, whereas those with higher values poorly respond to TT. (3) Monoleaflet valves lead to artifact on MDCT imaging. In particular, Bjork–Shiley and Sorin valves significantly degrade images so that they cannot be examined with 64-slice MDCT.

In conclusion, 64-slice MDCT imaging complements current echocardiographic methods and provides anatomic information and quantitative data that can help distinguish between pannus and thrombus and that help assessing whether masses are amenable to thrombolysis.

Acknowledgments

We thank Ubeydullah Deligönül, MD, Jefferson City Medical Group, Jefferson City, Missouri, for his significant contributions in drafting the article.

Disclosures

None.

References

Discrimination between pannus and thrombus in patients with prosthetic valve dysfunction (PVD) is mandatory because proper treatment differs according to pathogenesis. Surgery is the only therapeutic option for pannus removal. On the other hand, thrombolysis is reasonable for those with PVD because of thrombosis. Transesophageal echocardiography may not suffice in distinguishing between pannus and thrombus. In the current single-center, prospective, observational study, 64-section multidetector computed tomography proved accurate in this regard. Periprosthetic masses with high attenuation (Hounsfield Unit $\geq 145$) predict the presence of pannus formation with high sensitivity and specificity, and surgery should be favored. For those with a Hounsfield Unit $<145$, a diagnosis of thrombus is likely. Furthermore, the outcome of thrombolysis was also evaluated, and periprosthetic masses with low attenuation (Hounsfield Unit $<90$) were almost always completely lysable. However, most periprosthetic masses with intermediate attenuation (Hounsfield Unit $=90–145$) were only partially lysable. The findings of the current study may have implications for the management of PVD and potentially direct an individualized approach to patients with suspected PVD. As such, when multidetector computed tomography is integrated into current diagnostic methods for the evaluation of PVD, discrimination between pannus and thrombus and identifying periprosthetic masses amenable to thrombolysis may be feasible by measuring the attenuation value of these masses. Despite the limitations in imaging metal valvular prostheses, 64-section multidetector computed tomography not only identifies periprosthetic masses, but may also serve to further characterize these masses and guide treatment in patients with PVD.
Sixty-Four–Section Cardiac Computed Tomography in Mechanical Prosthetic Heart Valve Dysfunction: Thrombus or Pannus
Sabahattin Gündüz, Mehmet Özkan, Macit Kalçık, Ozan Mustafa Gürsoy, Mehmet Ali Astarcıoğlu, Süleyman Karakoyun, Ahmet Çağrı Aykan, Murat Biteker, Tayyar Gökdeniz, Hasan Kaya, Mahmut Yesin, Nilüfer Eksi Duran, Deniz Sevinç and Tahsin Güneysu

Circ Cardiovasc Imaging. 2015;8:
doi: 10.1161/CIRCIMAGING.115.003246
Circulation: Cardiovascular Imaging is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 1941-9651. Online ISSN: 1942-0080

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