Multidetector-row computed tomography imaging of prosthetic heart valves: clinical and experimental aspects
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Citation for published version (APA):

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CHAPTER 2

Comparison of Multidetector-Row Computed Tomography to Echocardiography and Fluoroscopy for Evaluation of Patients with Mechanical Prosthetic Valve Obstruction

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Am J Cardiol 2009;104:1128-1134
ABSTRACT

For evaluation of prosthetic heart valve obstruction echocardiography and fluoroscopy provide primarily functional information but may not unequivocally establish the cause of dysfunction. Our objective was to evaluate whether multidetector-row CT imaging (MDCT) could detect the morphological substrate for such functional abnormalities. Thirteen patients with 15 prosthetic valves, in whom prosthetic valve obstruction was suspected from echocardiography or fluoroscopy but no sufficient cause could be found, underwent ECG-gated MDCT. MDCT data were retrospectively reconstructed at every 10% of the ECG interval and analyzed using multiplanar reformatting in anatomically adapted planes. MDCT images were evaluated for morphologic prosthetic and periprosthetic abnormalities. Results could be compared to intraoperative findings or autopsy in 7 patients. MDCT found a morphological substrate for obstruction in 8 of 13 patients. MDCT findings compatible with obstruction were confirmed at surgery or autopsy in 6 patients. In a seventh patient, incomplete leaflet closure found with MDCT was confirmed at surgery. The most commonly identified causes for obstruction were subprosthetic tissue (6 patients) and abnormal anatomic orientation (3 patients). Despite an indication for surgery, 2 patients were not operated due to recurrent bacteremias and prohibitive comorbidity. MDCT detected leaflet motion restriction in 7 patients compared to 4 by fluoroscopy. Confirmation of leaflet restriction was available in 5 patients. MDCT missed a periprosthetic leak. In conclusion, this initial experience demonstrates that MDCT can identify causes of prosthetic valve obstruction that constitute indications for surgery but are missed at echocardiography or fluoroscopy.
INTRODUCTION

Cardiac ECG-gated multidetector–row CT (MDCT) is currently mainly used for coronary assessment \(^1\text{,}^2\) and has recently been demonstrated to allow for dynamic imaging of native cardiac valves.\(^3\text{-}\text{5}\) Recently, one study demonstrated the feasibility of measuring leaflet opening and closing angles of prosthetic valves.\(^6\) In addition, a Japanese group has been able to associate pannus formation to subprosthetic tissue seen on MDCT.\(^7\text{-}\text{9}\) We report our initial experience with 64 detector-row CT for assessing mechanical prosthetic valves in patients suspected of prosthetic valve obstruction (PVO). We evaluated the ability of MDCT to establish the cause of valve obstruction and assessed its impact on patient management.

METHODS

In this retrospective study we included 13 consecutive patients with 15 mechanical prosthetic valves who had undergone cardiac MDCT scanning between January 2005 and August 2008 and in whom PVO of unknown etiology was present. During the study period, 6 patients presented with either evident thrombotic obstruction or hemodynamic instability and were not included. Reasons for MDCT scanning were suspected coronary disease, evaluation of suspected aortic root pathology and evaluation of valve dysfunction. Interval between valve implantation and MDCT scanning ranged from 3 months to 16 years. Analysis of PVO was performed in patients with increased transprosthetic gradients (9 patients), impaired leaflet opening or closure (1 patient), or both (3 patients). A single patient with a normal transprosthetic gradient had persisting impaired leaflet opening after thrombolysis. Information on findings at echocardiography and fluoroscopy, patient management and pathological or surgical findings were obtained from patient records.

All patients had undergone at least 4 echocardiographic examinations including at least 1 transesophageal examination. These were performed or reviewed by 2 dedicated cardiologists with 8 and 20 years of experience in echo-Doppler diagnosis of prosthetic valve dysfunction. The interval between echocardiography and MDCT was less than 8 days in all but one patient (patient #5, 35 days). Fluoroscopy had been performed in all 13 patients.

All patients in this study were selected because of a PVO of uncertain etiology. Obstruction was defined as an elevated transprosthetic Doppler gradient or unexplained impaired opening or closing of leaflets. For aortic valves, Doppler measurements were performed in a 5 chamber transthoracic view, and for mitral valves Doppler measurements were done using transesophageal echocardiography. Effective orifice area was determined for the mitral valve using the pressure half-time method. In 12
of 13 patients the transprosthetic Doppler gradients were elevated compared to earlier measurements and reference values from the literature.\textsuperscript{10,11} In 1 patient with a normal transprosthetic gradient, a persisting restricted leaflet opening was present on fluoroscopy after thrombolytic treatment. The cause of obstruction was considered uncertain if echocardiography and fluoroscopy could not differentiate between various causes of obstruction (pannus, thrombus, structural valve failure) and the level (subprosthetic, prosthetic and supraprosthetic) of obstruction could not be clearly defined.

Concomitant findings at echocardiography, such as prosthetic and periprosthetic leaks (other than standard regurgitant jets) were also identified and it was noted whether these findings were considered indications for surgery by the treating physicians.

Findings at surgery or autopsy were considered the standard of reference (gold standard) and were available for 7 of the 13 patients. This included 4 patients operated for PVO only, 1 patient operated for combined PVO and periprosthetic leak and 1 patient operated for periprosthetic leak. One autopsy was performed in an additional patient who died of unrelated causes during preoperative evaluation.

Surgical indications related to PVO were structural valve failure, supra- and subprosthetic obstruction or an abnormal anatomic situation that was causing obstruction. Medical treatment was preferred if a thrombus was suspected. Indications for surgery that were not related to PVO included important periprosthetic leaks. Despite an indication for surgery, 2 patients were not operated. Reasons included prohibitive comorbidity and recurrent bacteremias. None of the patients with suspected patient-prosthesis mismatch were symptomatic, and were not deemed surgical candidates.

All patients underwent an ECG-gated contrast-enhanced scan of the heart on a 64 detector-row CT scanner (Brilliance 64, Philips Medical Systems, Cleveland, Ohio). The imaging volume was started approximately 2 cm above the aortic valve and ended at the base of the heart. Iodinated, nonionic contrast material (Ultravist, 300 mg iodine / mL; Bayer Healthcare Tarrytown, New York) was continuously injected intravenously followed by a saline chaser. Total contrast dose and injection rate were calculated individually based on patient weight and scan duration. A circular region of interest placed in the descending aorta was monitored in real time and as soon as the contrast enhancement in the aorta reached the predefined threshold of 100 Hounsfield units, the patient was instructed to maintain a breath hold. After 6 seconds, scanning was started and performed in a craniocaudal direction with simultaneous recording of the ECG trace.

CT scanning was based on a retrospectively ECG-gated data acquisition with 64 x 0.625 mm collimation, a scan pitch of 0.2 and a gantry rotation time of 420 milliseconds. Exposure parameters were 120 kVp tube voltage and 500-700 effective mAs tube current.
depending on patient size. If the heart rate was above 70 beats per minute, short acting 
beta-blockers (metoprolol, 5-20mg) were administered intravenously to reduce heart 
rate and improve image quality.

From the acquired scan data we reconstructed 10 3D-image datasets at every 10% of 
the R-R interval to cover the full heart cycle (0% to 90%). These 3D-datasets consisted 
of 0.9mm thick sections reconstructed at 0.7mm intervals. ECG-tube dose modulation 
was used in 3 patients (#6, 9 and 11). All 10 datasets were loaded simultaneously in 
the multi-planar cardiac viewer application, allowing simultaneous visualization in 
three orthogonal planes. Viewing planes were adjusted to standardized views that were 
analogous to common echocardiographic views. First, an imaging plane was aligned 
parallel to the valve ring to obtain a short axis view of the valve. Then, for long axis 
views, the longitudinal planes were adjusted perpendicular and parallel to the base of 
the anterior mitral leaflet i.e. the imaginary line between the fibrous trigones. Possible 
abnormalities were validated by repeating evaluation after rotation of the longitudinal 
axes by 45 degrees in the short axis of the prosthesis and by comparing with images 
in other ECG intervals. Subsequently, analysis of the leaflet motion was carried out 
by aligning the longitudinal planes perpendicular to the prosthetic valve leaflets. In 
bileaflet valves, opening and closure angles relative to the prosthetic valve ring were 
measured for each leaflet individually. Reading error was estimated at 4º. Measurements 
deviating more than 4º from manufacturer reference values were considered to 
represent restrictive motion. The best systolic and diastolic phases were used for angle 
measurement.

Two observers, a radiologist and a cardiac surgeon (with 3 and 2 year experience in 
reading cardiac CT scans) independently assessed and scored all scans in a standardized 
manner using commercially available analysis software (Philips Brilliance 3.0, Philips 
Medical Systems, Cleveland, Ohio). A third observer, a radiologist with more than 8 
years of experience with cardiac CT was consulted in case of questions regarding image 
interpretation. He also served as an arbiter in cases of disagreement between readers.

MDCT abnormalities compatible with obstruction were: (1) valvular masses, (2) 
sub- or supraprosthetic proliferation of tissue, (3) abnormal LVOT (for aortic valves), 
(4) an important deviation of the valve prosthesis from the normal annular plane. 
Periprosthetic tissue proliferation was defined as tissue extending beyond the prosthetic 
ring into the orifices of the valve. As little is known about the differentiation of thrombus 
and pannus on MDCT, attenuation values of these tissues were noted and compared to 
the histology.
CHAPTER 2 | CT for prosthetic valve obstruction

RESULTS

Thirteen patients (6 males, age range 35-84) underwent MDCT scanning. A total of 15 mechanical prosthetic valves were present. The group included 10 patients with isolated aortic valves 2 patients with aortic and mitral valves and 1 patient with a mitral prosthesis. One of the 2 patients with aortic and mitral prostheses had obstruction of both valves (#12). In total 14 of 15 valves were obstructed. Patient characteristics are summarized in Table 1.

The presence of important periprosthetic leaks constituted the primary indication for surgery in 2 patients (#10 and 12). Minor periprosthetic leaks (patients #8 and 9) were not considered a surgical indication.

MDCT imaging provided additional findings not detected by echocardiography or fluoroscopy in 9 of 13 patients (69%). A morphological substrate for PVO was found in 8 patients and in 10 of 14 valves. Surgery or autopsy (gold standard) was available in 6 of these 8 patients and confirmed CT findings in all cases.

The most common abnormal finding on MDCT was subprosthetic tissue overgrowth. It was found in 6 patients and confirmed in all 5 of these 6 patients in whom a gold standard was available. Subprosthetic tissue overgrowth was seen in 5 patients with aortic prostheses and in one with a mitral prosthesis (Figures 1 and 2). Although microscopic anatomy showed a combination of fibrous tissue and organized thrombus (3 patients), fibrous tissue (1 patient) and calcification (1 patient), no consistent differences in attenuation values could be found between the different tissues.

Profoundly altered anatomy caused PVO in 3 patients. We found 2 mechanisms of obstruction: narrowing of the LVOT (Figure 3, patients #11 and 12) and a tilted position of an aortic prosthesis after root reconstruction for endocarditis (Figure 4, patient #9). Narrowing of the LVOT to a diameter of 10 and 11 mm on the long axis view was considered significant in both patients 11 and 12. The mechanism of protrusion of the mitral prosthesis into the LVOT was confirmed in both patients at surgery and the operative strategy adjusted to ensure a wide LVOT. The patient with a tilted position of the aortic valve was not subjected to re-operation due to recurrent bacteremia. However, the tilt of 20° relative to the axis of the LVOT explained the high transprosthetic gradient [12]. Patient #12 with protrusion of the mitral prosthesis into the LVOT replacement had another mechanism of obstruction as well (subprosthetic tissue, see Table 1 and figure 2c).
### Table 1: Patient Characteristics

<table>
<thead>
<tr>
<th>Case index</th>
<th>Time after implant</th>
<th>Prosthesis type</th>
<th>Leaflet restriction on fluoroscopy</th>
<th>Echo Doppler findings</th>
<th>MDCT findings</th>
<th>Leaflet restriction on CT</th>
<th>Morphological substrate of obstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (78F)</td>
<td>14 y</td>
<td>MH 20 (A)</td>
<td>-</td>
<td>7.5/48</td>
<td>indeterminate</td>
<td>subprosthetic tissue</td>
<td>S (12º)</td>
</tr>
<tr>
<td>2 (70F)</td>
<td>15 y</td>
<td>MH 22 (A)</td>
<td>S(10º)</td>
<td>45/20</td>
<td>thrombus/pannus</td>
<td>subprosthetic tissue</td>
<td>S (10º)</td>
</tr>
<tr>
<td>3 (65F)</td>
<td>13 y</td>
<td>MH 22 (A)</td>
<td>-</td>
<td>60/40</td>
<td>indeterminate</td>
<td>subprosthetic tissue</td>
<td>S (10º)</td>
</tr>
<tr>
<td>4 (84F)</td>
<td>16 y</td>
<td>MH 22 (A)</td>
<td>S(15º)</td>
<td>60/27</td>
<td>thrombus/pannus</td>
<td>subprosthetic tissue</td>
<td>S (15º)</td>
</tr>
<tr>
<td>5 (33M)</td>
<td>10 y</td>
<td>OM 27 (A)</td>
<td>-</td>
<td>75/70</td>
<td>indeterminate</td>
<td>subprosthetic tissue</td>
<td>-</td>
</tr>
<tr>
<td>6 (53M)</td>
<td>15 y</td>
<td>DM 23 (A)</td>
<td>-</td>
<td>60/40</td>
<td>indeterminate</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7 (79F)</td>
<td>4 m</td>
<td>OM 19 (A)</td>
<td>-</td>
<td>60/40</td>
<td>PPM?</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8 (63M)</td>
<td>3 y</td>
<td>OM 21 (A)</td>
<td>-</td>
<td>50/30</td>
<td>PPM?</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9 (66M)</td>
<td>5 m</td>
<td>OM 21 (A)</td>
<td>-</td>
<td>80/40</td>
<td>PPM?</td>
<td>tilted prosthesis in LVOT</td>
<td>-</td>
</tr>
<tr>
<td>10 (35M)</td>
<td>3 m</td>
<td>SO 25 (A)</td>
<td>S(23º)</td>
<td>25/15</td>
<td>thrombus</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>11 (53M)</td>
<td>15 y</td>
<td>BS 23 (A)</td>
<td>-</td>
<td>75/45</td>
<td>indeterminate</td>
<td>LVOT narrowed by mitral valve</td>
<td>S (8º)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BS 29 (M)</td>
<td>11/4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>12 (66F)</td>
<td>16 y</td>
<td>DM 21 (A)</td>
<td>-</td>
<td>65/35</td>
<td>subaortic stenosis</td>
<td>LVOT narrowed by mitral valve</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DM 29 (M)</td>
<td>S(40º)</td>
<td>35/10</td>
<td>indeterminate</td>
<td>subprosthetic tissue</td>
<td>S (40º)</td>
</tr>
<tr>
<td>13 (36F)</td>
<td>4 m</td>
<td>CM 29 (M)</td>
<td>-</td>
<td>27/9</td>
<td>thrombus</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: additional findings by MDCT are italicized; prosthesis type: MH = Medtronic Hall tilting disc; CM = Carbomedics; DM = Duramedics; SO = Sorin Bicarbon; A = aortic; M = mitral; S = systolic restriction of leaflet motion; PPM = patient-prosthesis mismatch; LVOT = left ventricular outflow tract; D = diastolic restriction of leaflet motion; patients marked with an asterisk were not surgical candidates due to prohibitive comorbidity (patient #1) and recurrent bacteremias (patient #9).
FIGURE 1 | MDCT appearance and surgical findings of subprosthetic tissue proliferation involving a Medtronic Hall valve in patient #2. The arrows in the long axis (A) and short axis (B) views show a subprosthetic rim of tissue most prominent at the side of the left coronary artery (indicated by the circular mark). Note the artifacts caused by the valve material, which vary between phases and are frequently consisting of a bright and a dark component. The dark artifacts are indicated by asterisks. At surgery, the prominent subprosthetic rim at the side of the left coronary ostium was clearly evident (right arrow in C), and tissue was found interfering with normal valve leaflet motion (left arrow in C). After removal of the prosthesis (D), the subprosthetic tissue proliferation becomes even more evident. The dots indicate the level of the prosthetic ring and the arrows show the tissue overgrowth which consisted of fibrous tissue and organized thrombus.
Figure 2 | MDCT views of subprosthetic tissue causing obstruction. Despite lesser image quality the protrusion of tissue in the smaller opening of a Medtronic Hall tilting disc valve in a long axis (see arrows in A) and short axis view (B) is evident (patient #4). Subprosthetic tissue impaired the opening of a bileaflet mitral prosthesis (see arrow in C, patient #12). Note the varying CT densities of the tissue: in figures A and B it consisted of organized thrombus and fibrosis, and in C it was a completely calcified rim. Dark artifacts are indicated by asterisks. LA denoted the left atrium, LV the left ventricle.

Figure 3 | Echocardiographic and MDCT images of patient #12 with aortic and mitral valve prostheses and suspected obstruction of both valves. Long axis parasternal echocardiographic views show an abnormal contour of the LVOT with marked artifacts of the two prostheses with acceleration on Doppler and an estimated LVOT diameter of 1.56 cm (A). MDCT imaging in a long axis view perpendicular to the mitral valve (B) shows narrowing of the LVOT to 1.1 cm by a protruding mitral prosthesis. On the basis of these MDCT images, surgical strategy changed to ensure a wide LVOT. Transesophageal echocardiographic views were hampered by reflections of the mitral prosthesis and did not allow visualization of the LVOT. Asterisks denote the valvular artifacts which are characterized by their CT density (substantially above and below that of contrast-enhanced lumen or soft tissue). LA denotes the left atrium, and LV the left ventricle.
FIGURE 4 | Long axis views perpendicular (A) and parallel (B) to the anterior mitral leaflet demonstrating a considerable tilt of the prosthesis in the LVOT in patient #9. Following endocarditis, aorto-ventricular dehiscence had been repaired using a large pericardial patch at the level of the left coronary cusp. Due to the loss of the annular plane, the prosthesis had been attached to the pericardial neo-annulus and was tilted 20° in relation to the LVOT which reduced the effective orifice area.

FIGURE 5 | The opening angle in patient #10 as measured between the leaflets with fluoroscopy (A) was 138° (manufacturer reference value was 140°). With MDCT a closure angles of the individual leaflets were measured and found a difference of 5° (B, closure angles for each leaflet shown). At surgery (C), interference of leaflet closure was found to be caused by a long inverted suture knot (arrow). A periprosthetic leak, which constituted the primary indication for surgery, could not be reproduced with MDCT.
MDCT found restriction of leaflet motion in 7 patients with mechanical valves whereas fluoroscopy found 4 cases. Fluoroscopy failed to detect incomplete opening (systolic restriction) in 3 patients, and incomplete closure (diastolic restriction) in one. The latter patient was operated because of periprosthetic leakage. At surgery, an inverted suture knot was found to be entrapped between a leaflet and the ring (Figure 5) which explained the incomplete leaflet closure.

Among the remaining 6 patients, 4 underwent surgery with confirmation of MDCT findings. One patient with prohibitive comorbidity was treated conservatively. In patient #11 incomplete opening of the aortic valve was not confirmed at surgery but an important subvalvular obstruction in the LVOT was present.

MDCT detected 3 of 4 periprosthetic leaks seen at echocardiography. No abnormalities were found with MDCT in 4 patients (#6-8 and 13).

Image quality was generally good and diagnostic evaluation of even the tissue immediately surrounding the prosthetic valves was possible in 12 patients. Artifacts associated with the Bjork-Shiley valves limited interpretation of periprosthetic tissue in patient #11. However, narrowing of the LVOT due to protrusion of the mitral valve could be visualized.

Prior to MDCT, the etiology of obstruction in 6 of 13 patients was indeterminate. MDCT findings were considered indications for surgery in 8 of 13 patients. Indications were subprosthetic tissue overgrowth in 6 patients, abnormal anatomy in 3 patients. One patient (#12) had two different mechanisms of obstruction (see Table 1). In addition, with MDCT imaging, surgical strategy was changed in two patients (#11 and 12).

**DISCUSSION**

Our study, that describes our initial experience with MDCT, shows that purely morphological differentiation provided valuable additional findings in 8 of 13 patients with PVO. These additional findings constituted indications for surgery in 8 patients. Importantly, MDCT could directly visualize subprosthetic tissue proliferation in 6 patients, which is notoriously difficult to detect by other techniques. These findings were confirmed in all 6 patients in whom surgery or autopsy were available.

The ability of MDCT to visualize the morphological substrate of PVO reflects various advantages of MDCT compared to echocardiography. These advantages include less interference from valve components (especially in multiple valve replacement), a more complete overview of complex anatomy, and the separation of acquisition and evaluation. The latter becomes an advantage in difficult anatomy: despite a short acquisition time MDCT poses no limits on the time spent on post-processing and reinterpretation of
findings. The fact that we detected more leaflet restrictions with MDCT than fluoroscopy is surprising but might be explained by the fact that fluoroscopy is most effective when the view is perfectly in line with the leaflets. Such a projection may be harder to obtain in valves with curved leaflets (e.g. Sorin and Duromedics valves) and may even be impossible in certain leaflet orientations. Although the margin of error was estimated at 4°, this remains to be validated in further studies.

The experience with MDCT imaging of prosthetic valve dysfunction is scant. Teshima and coworkers used an 8 detector-row CT scanner to demonstrate the protrusion of St Jude pivot guards into a subprosthetic hypertrophic septum. A group of patients with incomplete opening of leaflets was found to be more likely to have abnormal tissue extending from the septum into the pivot guard. In 2 cases this was confirmed at reoperation and pannus was found. As we have employed a 64 detector-row CT scanner, the superior spatial and temporal resolution allowed us to visualize directly subprosthetic tissue and to measure opening and closure angles of individual leaflets. Konen and coworkers used a 64 detector-row CT scan to demonstrate the feasibility of visualizing prosthesis leaflet movement. By comparing MDCT and fluoroscopy they found promising results for bileaflet valves. They found that artifacts associated with Sorin and Bjork Shiley tilting disc valves impaired diagnostic imaging. We experienced similar limitations with the imaging of Bjork-Shiley valves. Konen and coworkers succeeded in detecting ventricular tissue that caused restriction of leaflet motion of a mitral prosthesis in 1 patient. Our series contains a similar finding in patient #12 (Figure 2c). Such a finding supports the added value of MDCT in an area that is usually “out of bounds” for echocardiography.

An important limitation of our study is the lack of a control group. Although the morphological criteria considered compatible with obstruction would hold true for echocardiography, there is little data on the normal MDCT appearance of prosthetic valves. In our experience, no differentiation between pannus and thrombus was possible on the basis of attenuation values. However, the use of MDCT in concert with echocardiographic findings proved to be of value in this initial experience.
REFERENCES


