Complications of Aortic Valve Surgery: Manifestations at CT and MR Imaging

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Aortic valve replacement accounts for a significant portion of cardiac surgeries in the United States. Despite advances in prosthetic heart valve design, surgical technique, and postoperative care, complications after aortic valve replacement remain a leading cause of morbidity and mortality. Routine surveillance of prosthetic heart valves with trans-thoracic echocardiography (TTE), transesophageal echocardiography (TEE), and fluoroscopy is important, as these techniques allow accurate detection of prosthetic valve dysfunction. However, echocardiography and fluoroscopy may not allow identification of the specific underlying cause, including paravalvular leak, dehiscence, endocarditis, obstruction, structural failure, pseudoaneurysm formation, aortic dissection, and hemolysis. Magnetic resonance (MR) imaging and computed tomography (CT) have an emerging role as diagnostic tools complementary to conventional imaging for detection and monitoring of complications after aortic valve replacement. The choice between CT and MR imaging depends on individual patient characteristics, the type of prosthetic valve, and the acuity of the clinical situation. In general, screening with TTE followed by TEE is recommended. When results of TTE and TEE are inconclusive, cardiac CT and MR imaging should be considered. The choice between these imaging techniques depends on the presence of patient-specific contraindications to CT or MR imaging.

Abbreviations: ECG = electrocardiography, ICD = implantable cardioverter-defibrillator, LVOT = left ventricular outflow tract, PVE = prosthetic valve endocarditis, SSFP = steady-state free precession, TEE = transesophageal echocardiography, TTE = transthoracic echocardiography

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Introduction

Acquired disease of the aortic valve is a common valvular problem for which surgery is indicated (1). The varied causes of aortic valve disease include congenital malformation, calcific degeneration, rheumatic disease, and connective tissue disorders (2). Treatment is primarily surgical or, more recently, transcatheter replacement of the diseased aortic valve. The latter minimally invasive technique has provided acceptable results, dramatically changing the natural history of the disease (3,4).

Despite advancements in prosthetic heart valve design, surgical technique, and postoperative care, complications after aortic valve replacement remain a substantial source of morbidity and mortality (Table 1). Complications of prosthetic heart valve placement range in chronicity, severity, and clinical manifestation. Self-limiting cases include postpericardiotomy or postperfusion syndromes, while life-threatening conditions such as infective endocarditis, refractory hemolytic anemia, systemic arterial embolization, or dysfunction of the prosthesis require immediate treatment (5). Many complications are frequently asymptomatic or have an insidious onset. This factor in combination with a patient population with other comorbid conditions often represents a diagnostic challenge. Therefore, a thorough evaluation of the prosthetic heart valve and perivalvular structures is necessary to define appropriate treatment.

After aortic valve replacement, transthoracic echocardiography (TTE) is the standard method for serial assessments of prosthetic heart valve function (6). However, TTE is limited by operator dependency, acoustic shadowing from the prosthetic heart valve, and—in a subset of patients—difficult conditions for sonographic evaluation including obesity and chronic obstructive pulmonary disease. Cardiac computed tomography (CT) and magnetic resonance (MR) imaging are important diagnostic tools for prosthetic heart valve disease and can provide clinical information complementary to that yielded by echocardiography.

In this review, we explore the role of cardiac CT and MR imaging in diagnosis of complications of prosthetic aortic valves. The CT and MR imaging appearances of a broad spectrum of prosthetic aortic valve diseases are presented, including paravalvular or valvular regurgitation, valve dehiscence, prosthetic valve endocarditis (PVE) and abscess formation, obstruction (thrombosis vs pannus), structural failure, pseudoaneurysm formation, aortic dissection, and hemolysis.

CT Technique

Multidetector CT is a novel diagnostic technique for cardiovascular imaging in many clinical situations, such as noninvasive study of coronary artery disease, ventricular function, and myocardial viability (7). Recently, it has also been used for detecting valvular heart disease. Several studies have demonstrated that multidetector CT allows one to identify the underlying cause of prosthetic heart valve dysfunction and further define treatment strategies (8). However, adequate knowledge of the normal function, complications, and imaging appearances of various types of prostheses is required for assessment of valvular dysfunction (9,10).

As with study of a native valve, multidetector CT evaluation of an aortic valve prosthesis requires electrocardiographic (ECG) gating to overcome motion artifacts related to opening and closing of the prosthesis. The contrast agent concentration needs to be above 300 mg/mL with an injection rate of at least 4–6 mL/sec to ensure good enhancement of the aorta and cardiac chambers. The heart rate should be less than 60–70 beats per minute, which may require administration of β-blockers in the absence of contraindications (11).

To study the kinetics of the prosthesis, retrospective ECG-gated reconstruction covering the entire cardiac cycle can be performed (12). Usually, a minimum of 10 phases is necessary for an optimal study that includes systole. Leaflet motion can be viewed in cine mode. Multiplanar reformation enables optimal visualization of cardiac structures and reduces obscuration of areas affected by streak artifacts from the metallic

<table>
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prosthesis. This problem can also be reduced by applying different kernels or increasing section thickness (9). Currently, newer multidetector CT scanners enable use of thinner collimation, producing images with better spatial resolution for detection of pathologic lesions.

There are many advantages to use of multidetector CT (Table 2). Although echocardiography provides functional information, essential exploration of the components of the prosthesis and perivalvular environment is often limited by the acoustic window in patients with obesity, chronic obstructive pulmonary disease, or reverberation artifacts related to the metallic components. Multidetector CT allows direct visualization of leaflet morphology, mobility, and function in the aortic valve prosthesis in these difficult situations (6,13,14). Multiphase ECG-gated retrospective reconstruction encompassing the entire cardiac cycle allows evaluation of the kinetics of cardiac chambers while maintaining “as low as reasonably achievable” doses of radiation by using radiation-reduction techniques such as electrocardiographic modulation functional imaging (15). Other potential advantages include rapid acquisition, collection of a three-dimensional dataset that permits reconstruction of the valve in any plane, and potential for wide availability during off-hours (16).

There are several limitations to use of multidetector CT for cardiac imaging (Table 2). The spatial resolution is superior to that of TTE but not to that of transesophageal echocardiography (TEE). The temporal resolution is inferior to that of TTE and TEE (17). Multidetector CT may not be ideal for evaluating all types of implanted prosthetic valves. For example, the Björk-Shiley and Sorin monoleaflet tilting-disk valves produce severe artifacts, which preclude CT assessment (10,18). Arrhythmias and heart rates greater than 75 beats per minute may lead to motion artifacts.

### MR Imaging Technique

Cardiac MR imaging is usually performed with ECG gating and breath-hold acquisitions to compensate for motion artifacts. Balanced steady-state free precession (SSFP) is a widely used pulse sequence. It provides excellent contrast between myocardium and blood with a superior signal-to-noise ratio. In an 8–12-second breath hold, SSFP can produce cine images with excellent temporal and spatial resolution. Evaluation of the cardiac valve and related jets, wall motion, and volume is possible when SSFP imaging is applied to the short-axis plane as well as long-axis two-, three-, and four-chamber planes.

Quantification of aortic regurgitation can be achieved by using velocity-encoded phase-contrast imaging across a plane, regardless of the orientation of the flow jet. The lack of ionizing radiation allows safe serial examinations—an important consideration in patients with chronic, progressive valvular disease. Most MR imaging sequences for assessing valvular heart disease are performed without intravenous contrast material. When contrast material is required—for example, to image prior myocardial infarction—gadolinium products are used, which are exceedingly safe in patients with normal renal function (14).

Multiple studies have demonstrated the safety of 1.5-T cardiac MR imaging of most cardiac valve prostheses, since the valve experiences minimal magnetic field interaction and heating (19). It is also safe at a field strength of 3.0 T. In fact, it is estimated that a force greater than a magnetically induced 4.7 T is needed to cause partial or total detachment of a heart valve (20).

Cardiac MR imaging has less of a role in evaluation of mechanical prostheses owing to local metallic imaging artifacts, but these are much less significant with bioprosthetic valves or annuloplasty rings. However, these artifacts can affect the homogeneity of the local magnetic field and influence the sensitivity of phase-encoded flow

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<td><strong>Advantages</strong></td>
<td><strong>Disadvantages</strong></td>
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<tr>
<td>High temporal and spatial resolution</td>
<td>Severe artifacts with certain prosthetic heart valves*</td>
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<tr>
<td>Three-dimensional dataset</td>
<td>Radiation exposure</td>
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<td>Rapid acquisition</td>
<td>Need for iodinated contrast material</td>
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<tr>
<td>Wide availability</td>
<td>Need for heart rate control</td>
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<td>(9)</td>
<td>Irregular heart rhythm† may lead to motion artifacts</td>
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*For instance, Björk-Shiley and Sorin monoleaflet tilting-disk valves.
†For instance, atrial fibrillation and ventricular extrasystoles.
measurements. Despite these challenges, leaflet motion and anatomic abnormalities can still be accurately assessed in many clinical settings, making cardiac MR imaging an emerging modality for evaluating valvular disease.

Overall, cardiac MR imaging may offer many advantages over echocardiography and nuclear techniques (Table 3). It requires less operator dependency in the acquisition of images and depends less on good acoustic windows. Most important, it is able to offer a comprehensive, detailed, and quantitative examination inclusive of valvular morphology and function, ventricular volumes and function, and associated anatomic structures (21).

Among the disadvantages of cardiac MR imaging, the most important is its limited use in patients with pacemakers or ICDs (21) (Table 3). Otherwise, cardiac MR imaging is safe in patients with almost all endovascular prosthetic devices, including intracoronary stents and prosthetic heart valves. The acquisition time can be lengthy and may be intolerable for patients with claustrophobia. Most prognostic data and guidelines still rely on echocardiography, although this is likely to change as more data are obtained on cardiac MR imaging for assessment of valvular disease (14).

Complications

Paravalvular or Valvular Regurgitation

Regurgitation is characterized by abnormal blood flow in the direction opposite to that of physiologic blood flow. Clinically, it is imperative to distinguish between physiologic and pathologic regurgitation. All mechanical prosthetic heart valves display a variable degree of backflow that is dependent on prosthesis design. This is considered physiologic and desirable. A limited amount of backflow is needed to close the mechanical valve (closure backflow); after valve closure, backflow is also present (leakage backflow), which helps prevent thromboembolism (17). On the other hand, biologic prosthetic heart valves have virtually no regurgitation from closure and leakage backflow.

Pathologic regurgitation can be further defined as valvular or paravalvular regurgitation. Valvular regurgitation is characterized by a greater than normal physiologic regurgitant volume, which can occur if any abnormal structure impedes disk or leaflet closure. For both biologic and mechanical prosthetic heart valves, the causes include thrombus, pannus formation, and infective vegetations. Biologic valves, specifically, may be more susceptible to intrinsic structural failure in patients less than 65 years of age. This can lead to valvular or paravalvular regurgitation. These complications are further elaborated on in their designated sections.

Paravalvular regurgitation occurs when blood flows abnormally through a channel between the prosthesis and annulus as a result of incomplete sealing. It is a common finding after aortic valve replacement surgery, occurring in up to 18% of patients when assessed with intraoperative TEE (22). Minor paravalvular leaks generally carry a benign prognosis and are well tolerated. Patients may be asymptomatic or have mild hemolytic anemia. Less than 1% of cases progress to clinically significant heart failure or severe anemia (22). If treatment is necessary, surgical or more currently transcatheter closure is possible.

Paravalvular leaks may be precipitated by dehisced sutures, improper implantation of the valve, or endocarditis-induced dehiscence. Of these causes, endocarditis-induced dehiscence is the most common (23). However, paravalvular leaks may occur without definite signs of dehiscence. In this situation, it has been suggested that surgically induced anatomic and hemodynamic changes contribute to paravalvular leaks. For

<table>
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<td><strong>Advantages</strong></td>
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<tr>
<td>Three-dimensional dataset</td>
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<td>High spatial and temporal resolution</td>
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<tr>
<td>More accurate assessment of biologic prosthetic heart valves</td>
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<td>No need for iodinated contrast material</td>
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<td>No exposure to ionizing radiation</td>
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<tr>
<td><strong>Disadvantages</strong></td>
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<tr>
<td>Poorer assessment of mechanical prosthetic heart valves due to valve-induced artifacts</td>
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<tr>
<td>Claustrophobia in some patients</td>
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<td>Need for ECG and respiratory gating</td>
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<td>Long acquisition time</td>
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<tr>
<td>Contraindicated in patients with specific medical implants (eg, pacemakers, ICDs*)</td>
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<td>Difficulty monitoring ill patients, as ECG is distorted by the magnetic field</td>
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*ICDs = implantable cardioverter-defibrillators.
Figure 1. Paravalvular leak in a 55-year-old man with a prosthetic aortic valve. Coronal oblique CT image at the level of the LVOT shows a small defect (arrow) at the periphery of the valve. The defect is continuous with the lumen of the LVOT and ascending aorta.

Figure 2. Paravalvular leak in an 81-year-old man with a prosthetic aortic valve. (a) Oblique coronal balanced SSFP MR image through the LVOT during end-systole shows a focal dephasing artifact at the site of the prosthesis. (b) Corresponding image obtained during end-diastole shows a regurgitant jet of dephasing turbulent flow (arrow) that originates eccentrically at the site of perivalvular leakage. The jet of dephasing signal arises laterally from the edge of the valve, not centrally as expected in aortic insufficiency.

Aortic paravalvular leakage is difficult to quantify at echocardiography if no obvious regurgitation jet can be identified. In this situation, MR velocity mapping can be a valuable diagnostic tool for measuring regurgitant volume. A study by Pflaumer et al (26) demonstrated that both flow and volume analysis with MR imaging led to similar estimates of the aortic regurgitant fraction. At MR imaging of the LVOT during end-systole and end-diastole, paravalvular leaks appear as focal dephasing artifacts adjacent to the prosthesis (Figs 2–4).

example, the surgical annulus and anatomic annulus are strikingly different. Current prostheses may modify the natural semilunar line of the leaflet attachment to a monoplanar circular shape. This can alter the anatomic relationship between the prosthetic ring and aortic wall, leading to paravalvular leaks (24).

Cardiac CT permits characterization of the cardiac, mediastinal, and perivalvular structures, which may be suboptimally visualized at echocardiography (25). At CT, a paravalvular leak typically appears as a contrast medium-filled structure adjacent to the valve area. It is continuous with the left ventricular outflow tract (LVOT) and ascending aorta (Fig 1).
Valve Dehiscence

Dehiscence—suture line breakdown leading to separation of the prosthetic valve from the annulus—is a serious complication of prosthetic heart valve replacement with grave consequences unless promptly diagnosed and corrected surgically. Risk factors for aortic valve dehiscence include bacterial endocarditis, aneurysm of the ascending aorta, degenerative regurgitation, and severe calcification of the native valve (27). Of these, infective endocarditis is the major reason for dehiscence. The infectious process is usually not confined to the prosthesis itself but may extend into nearby tissue to induce abscess formation and dehiscence (28). The clinical picture includes diastolic murmur, hemolytic anemia, and congestive heart failure.

Dehiscence generally manifests as paravalvular leaks or backflow of blood through a conduit formed by abnormal separation of the prosthesis and annulus. Mild paravalvular leaks are usually well tolerated, while severe leaks associated with complete dehiscence are detrimental. Thus, serial assessments in patients with paravalvular leaks are important to prevent a catastrophic outcome. Cardiac catheterization and angiography are valuable, but periodic surveillance with these invasive techniques is impractical and not without risk. Currently, two-dimensional echocardiography is most commonly used to monitor these patients (29).

During the immediate postoperative period, valve position and integrity may be assessed with chest radiography. This is useful for identifying pulmonary venous hypertension, the most frequent sign of prosthetic valve malfunction (30). In addition, a change in angulation of a valve of more than 6° in the aortic position is virtually diagnostic of dehiscence and warrants further investigation (30).

At CT, prosthetic valve dehiscence is detected with multiplanar reformatted images obtained through the LVOT (Figs 5, 6). Dehiscence appears as a gap between the aortic annulus and the opposing margin of the artificial valve that allows visualization of a continuous column of contrast material from the left ventricular cavity into the aortic root (31).
Figures 5, 6. (5) Dehiscence of a mechanical aortic valve prosthesis in a 60-year-old man. (a) Oblique coronal image from contrast material–enhanced ECG-gated CT shows separation of the prosthesis from the aortic annulus (white arrow). There is a small pseudoaneurysm associated with the area (black arrow). \( Ao = \) aorta. (b) Oblique axial image from contrast-enhanced ECG-gated CT shows the small pseudoaneurysm (arrow) associated with the prosthesis. \( LA = \) left atrium, \( RA = \) right atrium. (6) Dehiscence of a mechanical aortic valve prosthesis in a 54-year-old man. Axial (a) and parasternal long-axis (b) images from contrast-enhanced ECG-gated CT show separation of the prosthesis from the aortic annulus (arrow) at its posterior aspect.

At MR imaging, balanced SSFP sequences allow direct visualization of the aortic valve and identification of jets. As at CT, separation of the prosthesis from the aortic annulus is seen. The resulting aortic regurgitation usually appears as a jet of dephasing retrograde flow into the left ventricle (Fig 7). If necessary, valvular flow velocity mapping measurements enable further quantification of the regurgitation (32).
Prosthetic Valve Endocarditis and Abscess Formation

The risk of PVE is greatest during the 5 years after surgery (33). However, it can occur anytime postoperatively and is generally classified as early or late by using the cutoff of 2 months. The timing of infection reflects significant differences in the microbiology of PVE and treatment strategies (5). Early PVE is usually caused by perioperative contamination from the skin, the wound, or intra-vascular devices, with Staphylococcus epidermidis and S aureus the most frequently encountered organisms. In contrast, late PVE resembles native valve endocarditis, with streptococci the most common causative organisms.

With mechanical prostheses, infection often starts at the sewing cuff or from thrombi near the sewing ring (34). Common complications include paravalvular leaks, ring abscesses, and extension of the infection into adjacent tissues. In contrast, the pathogenesis of bioprosthetic valve infection is similar to that of native valve endocarditis. The infection is limited to the cusps and rarely involves the sewing cuff or leads to periprosthetic abscesses (34).

Fever is the most common symptom. In a patient with a prosthetic heart valve, fever is concerning for endocarditis until proved otherwise. Other findings include a new or changing murmur, dehiscence, systemic embolization, and congestive heart failure.

When clinical suspicion for infective endocarditis persists despite unconvincing imaging evidence at echocardiography, CT can be used to reevaluate the valvular apparatus with a specificity of 88% and sensitivity of 97% (35). Multidetector CT can demonstrate vegetations in the form of small, round, hypointense masses located on the sewing ring or leaflet component, usually on the ventricular surface of the prosthesis (Figs 8, 9) (36). However, artifacts from the metallic prosthesis can be misinterpreted as thrombi. The differential diagnosis for aortic masses is extensive and should be correlated to the clinical setting.

Several studies have demonstrated the ability of CT to demonstrate infective endocarditis–related complications such as large aortic root abscesses (37,38). The CT finding of a markedly thickened area around the aortic root is indicative of an aortic root abscess (Fig 10). Inflammatory changes and pockets of gas may be present (Fig 11). CT also enables crucial anatomic evaluation of the valve, coronary arteries, and aorta for preoperative planning if necessary (17).
Figure 8, 9. (8) PVE in a 62-year-old woman with a prosthetic aortic valve. Parasternal long-axis CT image shows a soft-tissue microlobulated process (arrow) about a prosthetic valve leaflet. Note the asymmetry of the position of the prosthetic valve leaflets as the masslike process obstructs the normal translation of the affected leaflet. (9) Bacterial endocarditis in a 65-year-old man approximately 1 year after aortic valve replacement. Three-chamber CT images during diastole (a) and systole (b) show diffuse nodular thickening of the leaflets (arrows) of a Carpentier-Edwards aortic valve. Pathologic analysis demonstrated aortic valve vegetations and methicillin-resistant *S. aureus* endocarditis.

Figure 10. Perigraft abscess after aortic valve repair in a 59-year-old man. Axial nonenhanced (a, c) and contrast-enhanced (b, d) chest CT images, obtained at two adjacent levels near the aortic valve, show fluid (black arrows) and inflammatory changes to the adjacent fat planes (white arrows in a and b) surrounding the surgical bed.
Currently, MR imaging does not play a significant role in assessing cardiac manifestations of infective endocarditis. Although case reports have shown that MR imaging can demonstrate some complications of endocarditis, such as aortic root aneurysms or abscesses, to our knowledge, large-scale studies have not been performed (39).

**Obstruction (Thrombosis vs Pannus)**

Thrombosis, pannus formation, and infective vegetations can cause prosthetic valve obstruction. If obstruction is suspected, echocardiography is the primary screening modality, allowing evaluation for a sudden rise in transvalvular gradient, decrease in prosthetic valve orifice area, or new regurgitant jet (40). However, this technique is insufficient for fully demonstrating the pathologic causes of obstruction. For example, echocardiographic differentiation between a thrombus and a pannus is particularly difficult but important for determining treatment. Prosthetic valve obstruction can manifest clinically as dyspnea, heart failure, or systemic embolization in the case of thrombosis.

The prevalence of obstructive thrombosis varies from 0.3% to 1.3%, while that of nonobstructive thrombosis can be as high as 10% (41). Thrombosis occurs with similar frequency in patients with bioprosthetic valves and patients with mechanical valves receiving appropriate anticoagulation therapy (42). The main factors contributing to thrombosis of a prosthetic valve are ineffective anticoagulation (43) and mitral valve position (44). Bioprosthetic valves usually require anticoagulation for the initial 3 months, while mechanical valves require lifelong anticoagulation. Aspirin is recommended for both types of prostheses. Thrombosis is more prevalent in the winter months, a fact that possibly coincides with increased plasma fibrinogen levels and viscosity (45). Once thrombosis is diagnosed, treatment is with surgery or thrombolysis.

Although less common, another cause of prosthetic valve obstruction is pannus formation, which occurs with a frequency of 0.2%–4.5% per patient year (43). It leads to variable degrees of obstruction and increases the likelihood of thrombus development (43). A pannus is believed to be fibrous tissue ingrowth originating from the left ventricular septum, with extension to the periannulus as a consequence of the healing response from the endocardium (46,47). Surgery is necessary for symptomatic patients.

The clinical history, the location of the mass, and specific CT findings can help differentiate a thrombus from a pannus. Pannus formation is usually of late onset, and gradual obstruction continues despite adequate anticoagulant treatment (48). For an aortic prosthetic heart valve, a pannus commonly develops on the ventricular side, whereas a thrombus often develops on the aortic side (17). At CT, several studies have demonstrated that a pannus and a thrombus can be distinguished on the basis of CT attenuation (49,50).
A pannus appears as a hypoattenuating structure extending from the ventricular wall, most frequently underneath the valve ring (ventricular side). Since a pannus is a reactive process starting at the ventricular wall that evolves to invade the prosthetic annular portion, its tissue attenuation should appear similar to that of the ventricular septum. Therefore, a pannus should have a Hounsfield unit value similar to that of the ventricular septum (51).

A thrombus also appears as a hypoattenuating structure, which often adheres to the prosthesis. In contrast to a pannus, it generally appears on the aortic side. A thrombus attenuates x-rays to a lesser degree than the ventricular septum (17). Thus, in selected cases in which results of echocardiography (TTE and TEE) are indeterminate, further imaging with CT can demonstrate the subprosthetic tissue attenuations, allowing better characterization of the pathologic lesion.

There is little literature on use of MR imaging for detection of aortic valve prosthesis obstruction. However, there was a case report of obstructive mechanical mitral valve dysfunction due to a thrombus. It included ECG-gated cine cardiac MR images showing asymmetric inflow to the left ventricle and irregular transvalvular regurgitation (52).

**Structural Failure**

Since the 1950s, more than 80 models of prosthetic heart valves have been developed, with variable longevity, hemodynamic profile, and thrombogenicity. Structural failure rate is another important characteristic. After aortic valve surgery, the structural failure rate is higher for bioprosthetic valves than for mechanical valves among patients less than 65 years of age (53). However, this difference disappears in patients greater than 65 years of age, with bioprosthetic valves and mechanical valves having similar low rates of structural failure. This finding has been attributed partly to decreased activity in the elderly, which imposes less mechanical stress on the bioprosthetic valve.

Structural failure of mechanical prosthetic heart valves is rare. The most notorious example is the Björk-Shiley convexo-concave valve, which was implanted in 86,000 patients between 1978 and 1986 before being withdrawn from the market because of outlet strut fracture and embolization of the disk. With the valve in the aortic position, the result was massive aortic regurgitation and often death (>90% of cases) (54). Twenty-two thousand survivors remain worldwide with continuing clinical concerns about outlet strut fracture. The incidence of this complication in this population is low and varies from 0.01% to 0.05% per patient year (54).

The prevalence of bioprosthetic valve failure is approximately 30% for heterograft valves and 10%–20% for homograft valves within 10–15 years (5). It generally results from leaflet degeneration (ie, tear or rupture of the valve cusps) or calcification. Other causes of structural failure of bioprosthetic valves include mechanical stress, immunologic rejection, or endocarditis. The majority of patients have severe regurgitation, while a minority of patients have severe stenosis (21). Patients often experience progressive onset of dyspnea and other symptoms of congestive heart failure.

CT allows identification of structural deterioration as a cause of regurgitation by providing anatomic information about leaflet morphology and function. This information is important for identifying pathologic processes such as poor coaptation of the valve leaflets or leaflet thickening (17). CT is also reliable for identification of degenerative aortic valve stenosis. Recent studies have shown the results of quantification of the aortic valve area with CT to be similar to those with the accepted diagnostic standard TTE (55). Other causes underlying poor functioning of the aortic prosthesis including patient-prosthesis mismatch or valve thrombosis can be simultaneously assessed (6).

In patients with aortic valve prostheses, MR imaging allows noninvasive evaluation of flow velocities in the ascending aorta with high temporal and spatial resolution. These flow profiles are clinically important, as they can provide information on valve function, prosthesis alignment, and the presence of transvalvular or paravalvular jets (56). Thus, even minor quantitative hemodynamic alteration in the valve due to structural failure can be assessed.

**Pseudoaneurysm Formation**

Pseudoaneurysm formation postoperatively is a common cause of late reoperation after procedures involving replacement of the aortic root or ascending aorta (57). By definition, an aneurysm is a focal dilatation involving all three layers of a blood vessel. In contrast, a pseudoaneurysm is generally caused by defects of the innermost
layers (tunicae intima and media), which cause abnormal continuity of blood flow and outpouching of the outermost layer (tunica adventitia). Infrequently, all three layers are injured, and severe hemorrhage is prevented by a thrombus or surrounding structures. Pseudoaneurysm formation has been reported to occur in 7%–25% of patients with composite grafts (58).

For example, occurrence of pseudoaneurysms in association with the Bentall technique has been ubiquitously reported in the literature (59). This procedure entails replacement of the aortic root and ascending aorta with a composite graft and insertion of a prosthetic aortic valve, with reimplantation of the coronary arteries into the graft. Preoperative risk factors include chronic hypertension, infection, connective tissue disorders, aortic calcification, and “blowout” at the aortotomy site (60). Pseudoaneurysms can develop after dehiscence of the suture line at the aortic annulus, coronary ostia, and proximal or distal graft anastomotic site. Repeat operation is often required unless the pseudoaneurysm becomes thrombosed.

The clinical symptoms range from no symptoms to nonspecific complaints of dyspnea and fatigue, which are secondary to reduced cardiac output or left ventricular volume overload (61).
Timely diagnosis of an aortic pseudoaneurysm is critical, as their natural history includes expansion with a possibility of aortic rupture. At plain chest radiography, a pseudoaneurysm of the ascending aorta should be considered in patients with mediastinal widening or an anterior mediastinal mass after aortic valve replacement (62). Immediate testing with two-dimensional echocardiography or TEE is imperative (63). Most pseudoaneurysms demonstrate color Doppler flow into the aneurysmal space with systolic expansion (63).

If an enlarged ascending aorta with an echo-free space around the aortic graft is seen, then CT or MR imaging should be promptly performed (64). However, at times the aorta is wrapped around the graft, particularly when the Bentall technique was used. This may appear as a linear echolucent space parallel to the aorta at two-dimensional echocardiography, but advance knowledge of this finding as well as evaluation with CT or MR imaging can help exclude a pseudoaneurysm (65). Once the diagnosis is established, it is important to evaluate the prosthetic valve and coronary ostia to assess the patency of the coronary circulation.

At CT or MR imaging, a pseudoaneurysm appears as a saccular or fusiform dilatation of the aorta. CT enables better equilibration of contrast material between the opacified aortic lumen and the unopacified sac than does aortography. More important, CT offers excellent resolution of aortic disease independent of contrast material concentration (Figs 12–14) (66). The presence of a pseudoaneurysmal neck and any associated thrombus is often discernible (Fig 15) (62).
Figure 14. Perigraft pseudoaneurysms in a 71-year-old woman with a prosthetic aortic valve. Axial (a) and sagittal oblique (b) maximum intensity projection CT images show two contained collections (white arrows) associated with the prosthesis (black arrow in b). These findings are consistent with pseudoaneurysms. \( Ao = \) aorta.

Figure 15. Perigraft pseudoaneurysm in a 60-year-old man with a prosthetic aortic valve. Coronal oblique (a), axial oblique (b, c), and sagittal oblique (d) CT images show a large pseudoaneurysm (white arrows) anterior and to the right of a ball-in-cage type prosthesis. The neck of the pseudoaneurysm is well visualized (black arrow in a and c). Partial thrombosis of the pseudoaneurysm is seen as peripheral lower attenuation within the sac. The rim calcification in the sinus suggests that this is a chronic postoperative pseudoaneurysm. \( Ao = \) aorta, \( LA = \) left atrium, \( LV = \) left ventricle, \( RV = \) right ventricle.
Cardiac MR imaging is also diagnostic and is particularly useful for distinguishing a pseudoaneurysm from other pathologic processes such as an abscess (67). Cardiac MR imaging allows precise definition of the location, dimensions, and neck of the pseudoaneurysm (Figs 16–18). Other complications including pseudoaneurysm leakage, compression of nearby structures, and
thrombus formation can also be detected. Several studies have suggested that cardiac MR imaging is the technique of choice for monitoring the aorta after surgery (21).

The treatment of pseudoaneurysms usually requires reoperation, as they may expand, compress, and form a substrate for persistent infection or embolism. Preoperative cardiac CT and MR imaging allow accurate delineation of the complex anatomy and appropriate surgical planning to prevent laceration of major structures and blood loss (59). When the pseudoaneurysm is located on the ascending aorta or aortic arch, median sternotomy is the preferred approach. However, if the pseudoaneurysm is near the undersurface of the sternum, a right anterior thoracotomy is often performed (57).

Aortic Dissection
Aortic valve replacement is an independent risk factor for type A (proximal) aortic dissection, which is estimated to occur in 0.6% of cases postoperatively (68). An aortic dissection is caused by a tear in the aortic intima. This defect enables continuity of blood flow from the true lumen through a false lumen formed between the intima and media of the blood vessel.

There appears to be no relationship between type A dissection after aortic valve replacement and the surgical technique. Rather, aortic wall fragility, aortic regurgitation, and aortic wall thinning were identified as independent predictors of late aortic dissection, with associated probabilities of 22%, 14%, and 7%, respectively. When more than one risk factor exists, there is a synergistic effect (68). In these situations, both the ascending aorta and aortic valve should be replaced. Patients usually present with abrupt onset of severe chest pain.

The estimated sensitivity and specificity of CT for diagnosis of aortic dissection are 98% and 87%, respectively (69). Aortic dissection is identified by the presence of an intimal flap separating the true and false lumina (Fig 19) (70). Other clues to the diagnosis include ulcerlike projections of contrast material, widening of the aortic lumen, displaced intimal calcifications, and compression of the true lumen by the false lumen (70). Additional benefits of CT examination include characterization of any intraluminal thrombus or pericardial effusion, wide accessibility, and rapid acquisition in this emergent situation.

Cardiac MR imaging plays a major role in diagnosis and assessment of aortic dissection. Studies have demonstrated that MR imaging can have sensitivity and specificity of up to 100% (69,71). As with CT, aortic dissection is identified at MR imaging by the presence of a double lumen separated by an intimal flap. Moreover, MR imaging allows determination of the differential flow velocity of
Figure 19. Paravalvular abscess and dissection of the ascending thoracic aorta in a 70-year-old man after aortic valve replacement. Coronal oblique CT image shows a paravalvular collection (white arrows) that has continuity with the lumen of the LVOT. There is a dissection flap (black arrow) that begins just distal to the origin of the left main coronary artery (*). It extends to the descending aorta (not shown).

each lumen, involvement of arch vessels, extent of aortic regurgitation, and location of any secondary tears. Other suggestive but nondiagnostic features include widening of the aorta and thrombosis of the false lumen (71). However, hemodynamic instability and lengthy acquisition time may limit use of MR imaging in certain patients. Thus, it is recommended that MR imaging be used in hemodynamically stable patients and TEE be used in hemodynamically unstable patients (69).

Hemolysis
Hemolysis due to mechanical damage is a problem with mechanical prosthetic heart valves, especially the ball-cage or bileaflet designs (72). When present, it is usually mild and subclinical and is evidenced by schistocytosis in a peripheral smear, elevated lactate dehydrogenase level, decreased serum haptoglobin level, and reticulocytosis. Severe hemolytic anemia is usually indicative of another underlying process such as a paravalvular leak, infection, or obstruction.

Patients with hemolytic anemia should be treated with iron, folate, and blood transfusions. Untreated anemia worsens the hemolysis because the decreased blood viscosity and increased cardiac output further potentiate the severity of the hemolysis. Severe, refractory anemia requires surgical intervention, but if surgery is contraindicated, use of β-blockers may help reduce the degree of hemolysis (73).

Conclusions
Postoperative complications of aortic valve surgery remain a substantial source of morbidity and mortality. Thus, routine surveillance of prosthetic heart valves with TTE, TEE, and fluoroscopy is important. These techniques allow accurate detection of prosthetic valve dysfunction but may not permit identification of the specific underlying cause, including dehiscence, endocarditis, pseudoaneurysm formation, paravalvular leak, aortic dissection, obstruction, and structural failure. Recently, CT and MR imaging are becoming widely available and increasingly popular as diagnostic tools complementary to echocardiography and fluoroscopy. They allow superior anatomic visualization of the perivalvular environment as well as leaflet morphology, mobility, and function.

The choice between cardiac MR imaging and CT depends on individual patient characteristics, the type of implanted prosthetic valve, and the acuity of the clinical situation. Advantages of cardiac CT include less operator dependency, rapid acquisition, and wide availability. However, the requirements of use of iodinated contrast medium and a heart rate less than 60–70 beats per minute may preclude its use in patients with renal failure and irregular heart rhythms (eg, atrial fibrillation). Cardiac CT may not be ideal for evaluation of all types of implanted prosthetic valves. For example, the Björk-Shiley and Sorin monoleaflet tilting-disk valves produce severe artifacts, which preclude CT assessment. Cardiac CT also entails radiation exposure.

Advantages of cardiac MR imaging include absence of radiation exposure and no need for iodinated contrast material or heart rate control. These qualities enable it to be used for serial examinations, in which cumulative radiation exposure is a concern, and in patients with renal dysfunction. However, limitations of cardiac MR imaging include greater operator dependency and longer acquisition times. In addition, it is contraindicated in patients with medical devices (eg, pacemakers, ICDs, aneurysm clips). However, it is safe to use in patients with coronary stents.
In general, we recommend screening with TTE followed by TEE in patients with clinical suspicion of prosthetic heart valve dysfunction. When results of TTE and TEE are inconclusive, use of cardiac CT and MR imaging should be considered. If there are contraindications to CT, then MR imaging should be used and vice versa (Fig 20).

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References


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At CT, a paravalvular leak typically appears as a contrast medium–filled structure adjacent to the valve area.

Dehiscence appears as a gap between the aortic annulus and the opposing margin of the artificial valve that allows visualization of a continuous column of contrast material from the left ventricular cavity into the aortic root.

Multidetector CT can demonstrate vegetations in the form of small, round, hypoattenuating masses located on the sewing ring or leaflet component, usually on the ventricular surface of the prosthesis.

For an aortic prosthetic heart valve, a pannus commonly develops on the ventricular side, whereas a thrombus often develops on the aortic side.

At CT or MR imaging, a pseudoaneurysm appears as a saccular or fusiform dilatation of the aorta.