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CT of valvular heart disease

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Abstract

Although the incidence of valvular heart disease is significantly less than before the introduction of antibiotic therapy, chronic mitral and aortic valve disease continues to be found in the adult population. CT examination reveals characteristic chamber volume and myocardial mass changes expected in patients with valvular obstruction and regurgitation. Furthermore, CT provides sensitive visualization of annular and valve leaflet calcification, both of which are important findings for determining the presence of disease and estimating the significance of valvular dysfunction identified on examination. Although CT is by no means the first diagnostic modality to be employed in management of patients with valvular heart disease, it does reveal the sequelae of such disease, and may, in fact, provide insight into the significance of clinical or echocardiographic findings. Improved temporal resolution will increase the accuracy of CT diagnosis, and further expand its use for diagnosing and managing patients with cardiac disease in general, and valvular heart disease, in particular.

Introduction

Antibiotic therapy has resulted in a significant decrease in the incidence of rheumatic valvular heart disease in the US and Western Europe. Coincident with the decrease in rheumatic disease, there has been an increase in age-related degenerative valvular heart disease [1, 2]. Total annual mortality due to valvular heart disease in the US is nearly 20,000 patients per year [3]. Sixty percent of these deaths is the result of aortic valve disease; the remainder is mostly related to mitral valve disease. Pulmonary and tricuspid valve disease is rarely the cause of death. However, tricuspid regurgitation, secondary to pulmonary hypertension remains prevalent, and is not uncommonly encountered in clinical practice. Traditionally, it is unusual for CT to be employed as a first line of diagnosis in these patients. However, CT examination provides important morphologic and physiologic information concerning chamber size, myocardial mass, and pulmonary blood flow and pressure [4]. Furthermore, CT is exquisitely sensitive to the detection of annular and valve leaflet calcification. Very fast electron-beam (EBCT) and spiral multidetector (MDCT) scanners stop cardiac motion, and allow accurate and reproducible estimates of valvular calcium concentration [5, 6].

The role of CT scanning for detection of valvular heart disease will be dependent upon the value of assessing calcification in a patient with valve dysfunction. Nevertheless, morphologic changes in patients undergoing CT examinations for other indications may be detected. In this review, we will discuss the changes evident which form the basis for diagnosis of valvular heart disease, emphasizing the role of CT for calcium detection and quantitation.

Aortic stenosis

Calcific aortic stenosis is the most frequent reason for cardiac valve replacement. It may result from gradual progressive calcification of a congenitally bicuspid valve, or "degenerative" calcification of a

morphologically normal (tricuspid) valve. Interesting similarities between aortic stenosis and atherosclerosis have been reported [7–9]. Both conditions are more prevalent with increasing age, and both aortic stenosis and atherosclerosis demonstrate associations with gender, hyperlipidemia, hypertension, diabetes, and smoking. Calcific aortic stenosis is usually seen in patients over the age of 65 years. Mild valvular thickening affects 25% of adults older than age 65. Aortic stenosis affects between 1 and 3% of elderly patients [10]. As our population ages, the number of individuals with aortic stenosis is sure to rise as well. Aortic sclerosis is a term usually used to indicate the presence of irregular areas of focal thickening on the aortic valve annulus or leaflets which do not cause obstruction of left ventricular ejection (Figure 1). Calcific aortic stenosis and aortic sclerosis are due to a common disease process. In individuals with Doppler echocardiographically determined transaortic flow velocity <2.5 m/s, aortic sclerosis is used to describe the valvular abnormality. If transaortic flow velocity exceeds 2.5 m/s, which implies a hemodynamically significant obstruction, then the term aortic stenosis is utilized. Thus, the two terms reflect the continuum of morphologic abnormality to clinically significant, obstructive aortic valve disease.

The CT diagnosis of aortic stenosis is based upon the demonstration of left ventricular hypertrophy, mild-to-moderate dilatation of the ascending aorta (''post-stenotic dilatation''), and calcification of the aortic valve (Figure 2). Depending upon the severity and chronicity of the valvular obstruction, left ventricular thickening is variable. In patients

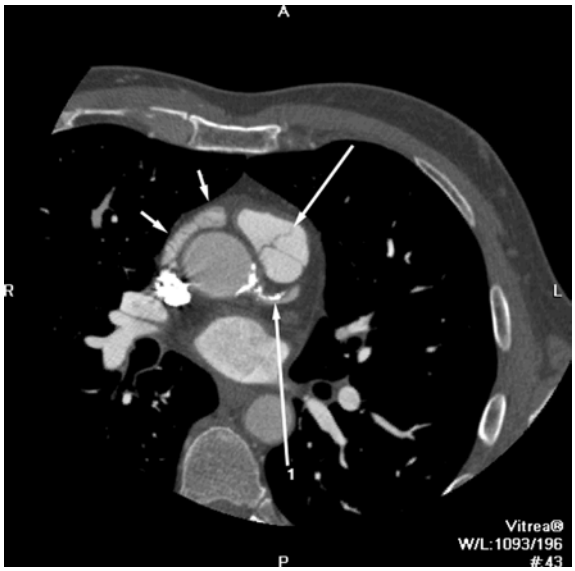

Figure 1. Aortic Sclerosis. Axial images from a contrast-enhanced multidetector CT examination from a 67 year old man with no aortic valve gradient. (a) Image through the right atrial appendage (short arrows) and pulmonary valve (long arrow). Notice the heavy calcification of the aortic root and left main coronary artery (arrow 1).

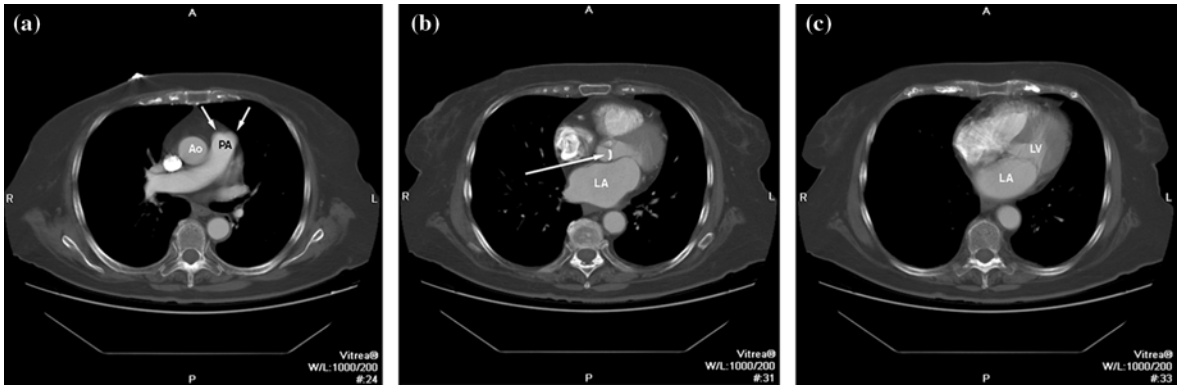

Figure 2. Axial images obtained from an ungated contrast-enhanced multidetector CT examination from an 83 year old woman with aortic stenosis. (a) Section through the sinuses of Valsalva of the main pulmonary artery (arrows). At this level, the ascending aorta (Ao) is greater in caliber than the main pulmonary artery (PA). (b) Section through the aortic valve and left atrium (LA). The calcificed aortic valve leaflet (arrow) is identified as a curvilinear high attenuation within the aortic annulus. (c) Section through the LA and left ventricle (LV). The left ventricular myocardium is thickened. The heart is not enlarged.

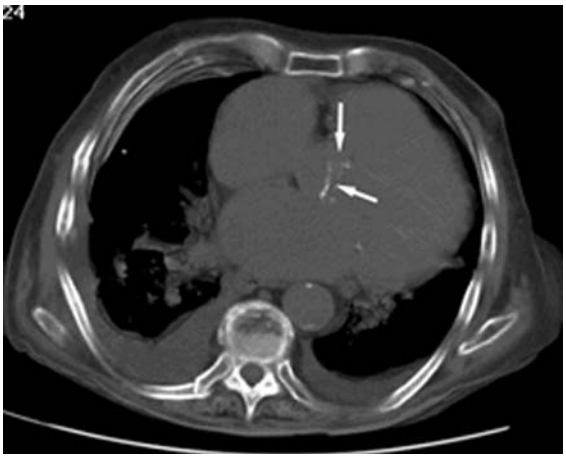

Figure 3. Non-contrast-enhanced multidetector CT examination from a 60 year old man with heart failure and a bicuspid valve aortic stenosis. Notice the faint calcification (arrows) along the commissural edges of the valve leaflets.

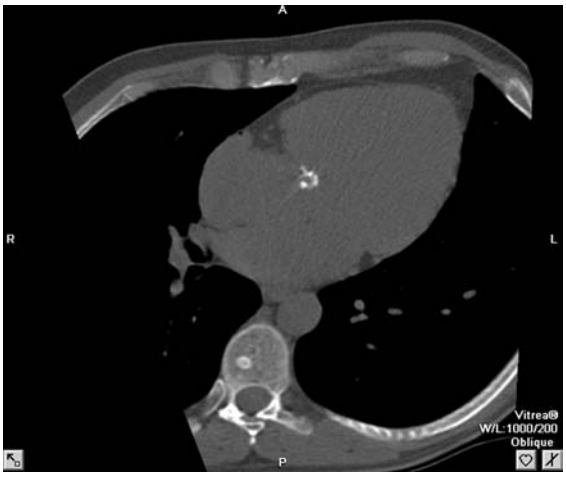

Figure 4. Horizontal long axis reconstruction from a non-contrast-enhanced electron-beam CT examination in a 30 year old man with coarctation of the aorta (not shown) and congenital bicuspid aortic valve. Mild curvilinear calcification near the geometric center of the heart characterizes this abnormal leaflet.

with congenital aortic valve disease, turbulence commencing in the newborn period causes an early fibrocalcific process, which results in thickening and calcification of the valve leaflets early (Figure 3). Calcific deposits are commonly distributed along the commissural edges of the leaflets, and calcification, in general, is not severe (Figure 4). Acquired degenerative calcific aortic stenosis results in greater calcification (heavier, more extensive calcium deposits). This disease is commonly associated with calcification of the aortic annulus as well as the leaflets.

Patients with symptomatic aortic stenosis (angina, heart failure, or syncope) are treated by prompt surgical valve replacement. Successful aortic valve replacement markedly improves prognosis in these individuals. Although patients with asymptomatic aortic stenosis have a relatively good prognosis, a subgroup of these patients may have a more severe form of this disease. Approximately 1–2% of asymptomatic patients with aortic stenosis die suddenly, or exhibit a rapid progression to the symptomatic state, and then on to sudden death [11, 12]. A wide range of degrees of aortic valve calcification is found in individuals with severe asymptomatic aortic stenosis. Nevertheless, those with the most aortic valve calcification have the worst prognosis [13].

Demonstration of aortic valve calcification on plain film examination indicates clinically significant aortic valve stenosis [14–16]. In nearly 90% of patients older than 65 years of age, aortic valve calcification is due to a chronic degenerative process [17]. Among individuals younger than 65 years, aortic valve calcification is usually associated with a congenitally bicuspid aortic valve [16]. In a review of 109 patients who underwent computed tomography and echocardiographic examination, Lippert et al. [18] found incidental aortic valve calcification in 30% of patients. Valvular calcification was significantly more prevalent in older individuals; nearly 50% of subjects greater than 75 years of age had aortic valve calcification on CT exam. These authors also found aortic valve calcification in 15% of subjects less than 55 years of age, as well. Use of fast CT scanners has provided adequate temporal resolution to quantitate aortic valve calcification, and thus allow reproducible investigations into its clinical significance. Shavelle et al. [19] retrospectively compared EBCT-derived measurements of aortic valve (aortic root and leaflet) calcification with Doppler echocardiography in 48 patients who had both EBCT

and echocardiography performed within 6 months. They found that individuals with higher aortic valve calcium scores were associated with higher aortic valve jet velocities, and that a valve score of 150 (calculated in a manner analogous to a volumetric coronary calcium score) was 100% sensitive for discriminating between valve jet velocities <2.5 m/s from those >2.5m/s.

Willmann et al. [20] investigated the value of non-contrast-enhanced and contrast-enhanced retrospectively ECG-gated multidetector CT examinations of the aortic valve for characterizing aortic valve morphology and degree of calcification in patients referred for aortic valve replacement for aortic stenosis. They compared their results with Doppler echocardiograms and observations made at the time of surgery. Aortic valve calcification was graded on a 1+ to 4+ scale, the latter being most severe. These authors found that contrast-enhanced MDCT was superior to non-contrast-enhanced MDCT for characterization of an abnormal valve as either bicuspid or tricuspid, and for determination of aortic annulus caliber. They also found that there was no difference between non-contrast-enhanced scans and contrast-enhanced scans for assessing the degree of aortic valve calcification. Furthermore, they found no difference in the strong correlation between the mean aortic valve gradient, as assessed by Doppler echocardiography, and the degree of aortic valve calcification, whether calcification was determined on a non-contrast-enhanced or a contrast-enhanced CT examination.

Kaden et al. [21] reviewed the EBCT scans of 40 consecutive patients with Doppler echocardiographically documented calcific aortic stenosis referred for coronary calcium screening. All patients included in this study had a tricuspid aortic valve and a maximal transvalvular gradient <20 mm Hg. In this study, image pixels with attenuation values ≥130 Hounsfield Units were called calcifications. Although these authors found that their measurements of aortic valve calcium was very accurate (interscan reproducibility, 7.9%; interobserver variability about 3.1%), the correlation between aortic valve calcium and aortic valve area ($R = -0.61$) was relatively weak. In a similar study, 50 patients with echocardiographic evidence of aortic valve calcification underwent two non-contrast-enhanced MDCT examinations, and the authors [22] assessed the accuracy of an interpolative method [23] for aortic valve calcium volume quantitation as well as the relationship between aortic valve calcium values and echocardiographically determined markers of the severity of aortic stenosis. These authors found good reproducibility of repeated aortic valve calcium volume measurements and a close, but non-linear correlation between aortic valve calcium volume and pressure gradient across the stenotic valve and derived aortic valve area. That is, they found a highly significant and strong correlation between the log of echocardiographically derived aortic valve area (AVA) and the log of aortic valve calcium volume (log AVA $= -0.3741$ log aortic valve calcium volume $+1.09$, $R = 0.835$, $p < 0.0001$), as well as the log of maximal aortic valve gradient (VG) and the log aortic valve calcium volume (log VG $= 0.434$ log aortic valve calcium volume $+0.38$, $R = 0.88$, $p < 0.0001$). Despite the good correlation between both valve area and valve gradient with calcium volume, they also noted that the range of valvular calcium values in patients with severe aortic stenosis (valve area <1.0 cm^2) was very broad.

In a sub-study of the **S**cottish **A**ortic stenosis and **L**ipid-lowering **T**herapy, **I**mpact on **RE**gression (SALT-IRE) trial that is evaluating the effects of lipid-lowering therapy on the rate of progression of aortic stenosis, Cowell et al. [25], evaluated 157 patients with aortic stenosis by Doppler echocardiography and non-contrast-enhanced MDCT. In this study, the investigators found a strong correlation between aortic valve calcium score and Doppler echo-derived post-valve velocity, as well as the mean and peak aortic valve gradient. However, they found only a weak correlation between aortic valve calcium and aortic valve area. When they stratified patients according to the quintiles of valve calcification (expressed in arbitrary units), they found a progressive increase in peak post-aortic valve velocity. All patients with severe aortic stenosis (post-valve velocity >4 m/s) had an aortic valve calcium score >3700. Using this threshold for aortic valve calcification, they found a 100%

negative predictive value for the detection of severe aortic stenosis.

There is a strong association between aortic valve calcification and the severity of aortic stenosis. MDCT and EBCT may be used to characterize an aortic valve as either bicuspid or not, and to estimate the severity of the valvular obstruction. Furthermore, the accuracy of these measurements supports use of fast CT as both a clinical and research tool. Early detection and characterization of aortic valve calcification by CT may be the basis for initiation of medical therapy to arrest progression, and perhaps reverse the disease process [27, 28].

Aortic regurgitation

CT diagnosis of aortic regurgitation is based upon recognition of left ventricular and aortic dilatation (Figure 5). Thus, milder forms of the disease may be underdiagnosed, and grading of the severity of the valvular dysfunction based upon morphologic changes of the left ventricle and aorta is innaccurate. In individuals with aortic regurgitation, CT may be helpful by demonstrating the severity and extent of aortic dilatation. That is, the severity of valvular dysfunction is reflected by the size of the aortic caliber, as well as how far toward the aortic arch the aortic dilatation extends.

Mitral valve disease

Calcification of the mitral annulus is commonly found in the elderly (more commonly among elderly women), and in association with standard cardiovascular risk factors [27], as well as systemic hypertension, aortic stenosis, renal failure, and diabetes [28, 29]. It may be associated with mitral insufficiency [30], but dysfunction is only mild to moderate, and individuals rarely need intervention. Calcific deposits are large, irregular, and form the outer margin of the posterior atrioventricular ring (Figure 6). In some individuals, CT examination has revealed an association between mitral annular calcification and coronary artery disease [31].

Morphologic changes in the heart in patients with chronic mitral stenosis result from chronic left atrial outflow obstruction. This causes left atrial and left atrial appendage enlargement in face of a normal left ventricle. Primary calcification of the atrial wall is almost always caused by chronic rheumatic disease (Figure 7). The chronic left atrial hypertension results in pulmonary vein dilatation, and eventually in pulmonary hypertension, as manifested by central pulmonary artery dilatation and right ventricular hypertrophy. In chronic disease, right ventricular and right atrial dilatation ensues, accompanied by characteristic clockwise

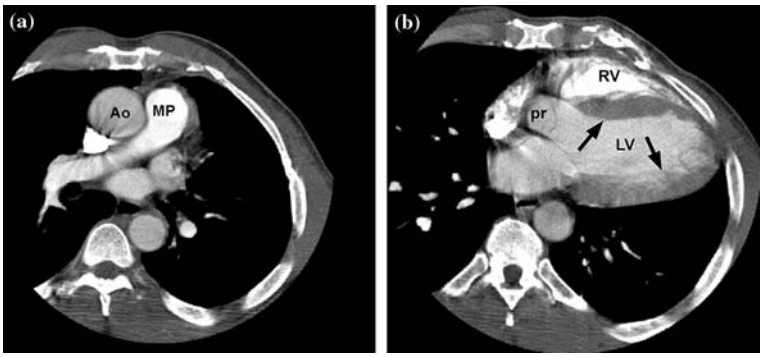

Figure 5. Contrast-enhanced, non-ECG-gated multidetector CT examination from a 56 year old man with moderate, chronic aortic regurgitation. (a) Section through the main (MP) and right pulmonary arteries and ascending aorta (Ao). The Ao is dilated; it is greater in caliber than the MP. (b) Image obtained through the posterior right aortic sinus of Valsalva (pr). Not only is the left ventricle (LV) dilated, but it is hypertrophied (arrows) as well. The normal-size right ventricle (RV) is labeled.

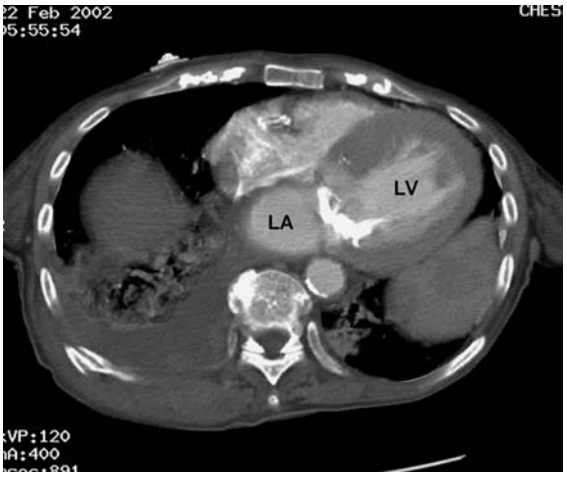

Figure 6. From a contrast-enhanced non-ECG-gated multidetector CT examination in an 81 with shortness of breath. Image obtained through the inferior aspect of the posterior atrioventricular ring. Interposed between the inferior aspect of the left atrium (LA) and the moderately hypertrophied left ventricle (LV) is the thick, irregular calcification of the mitral annulus.

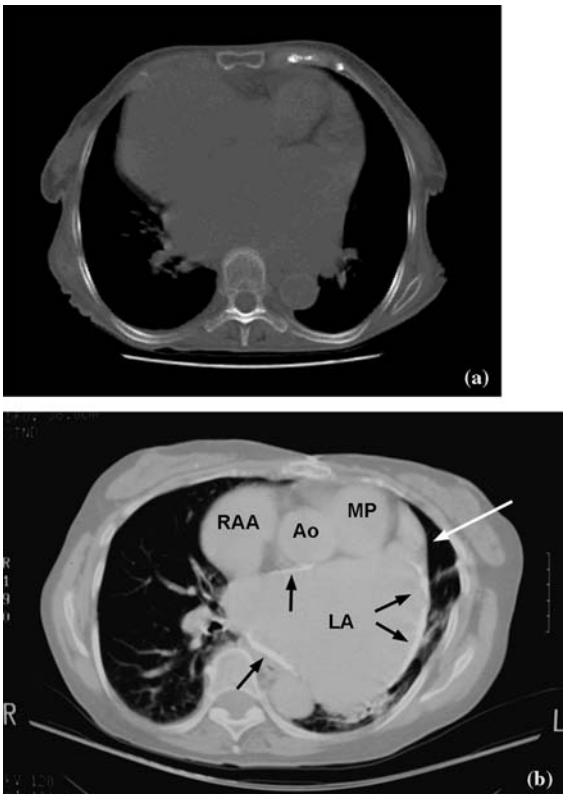

Figure 7. Two patients with chronic rheumatic mitral stenosis. (a) Non-ECG-gated, non-contrast-enhanced CT examination from a 64 year old man. The dilated left atrium (LA), right atrial appendage (RAA) and left atrial appendage (arrow) are border-forming, and thus readily identifiable. The main pulmonary artery (MP) is greater in caliber than the ascending aorta (Ao), indicating pulmonary hypertension. (b) Non-ECG-gated, contrast-enhanced CT examination from a 59 year old man. Similar chamber abnormalities are seen here, as well. In addition, notice the left atrial calcification (black arrows).

cardiac rotation. Right ventricular failure in these patients is manifested by changes caused by right atrial hypertension; i.e., coronary sinus, inferior vena cava and hepatic vein and azygos vein dilatation. Pleural and pericardial effusions as well as ascites may be encountered.

Acute mitral regurgitation does not result in alteration of cardiac chamber size; the heart may appear normal. However, the predominant findings are the changes of severe left atrial hypertension and interstitial pulmonary edema. Pleural effusion, alveolar infiltrates and pericardial effusion are commonly found. In patients sustaining acute myocardial infarction, coronary arterial calcification may be evident (Figure 8). In individuals with chronic mitral regurgitation, adaptation of the left atrium and left ventricle to the volume load results in left atrial and left ventricular dilatation, with less severe pulmonary vascular congestion, and rarely, if ever, pulmonary hypertension. Thus left atrial and ventricular dilatation is the rule. Left ventricular mass increases with the increased chamber volume, resulting in thickening of the left ventricular myocardium. Pulmonary arterial dilatation and right heart dysfunction are less commonly seen in these compensated patients.

Tricuspid valve disease

Tricuspid regurgitation results in right atrial and right ventricular dilitation and, as described above, clockwise cardiac rotation (Figure 9). The etiology of the valvular dysfunction can usually be inferred from associated morphologic abnormalities. For example, dilatation of the pulmonary arteries indicates that pulmonary hypertension mediates

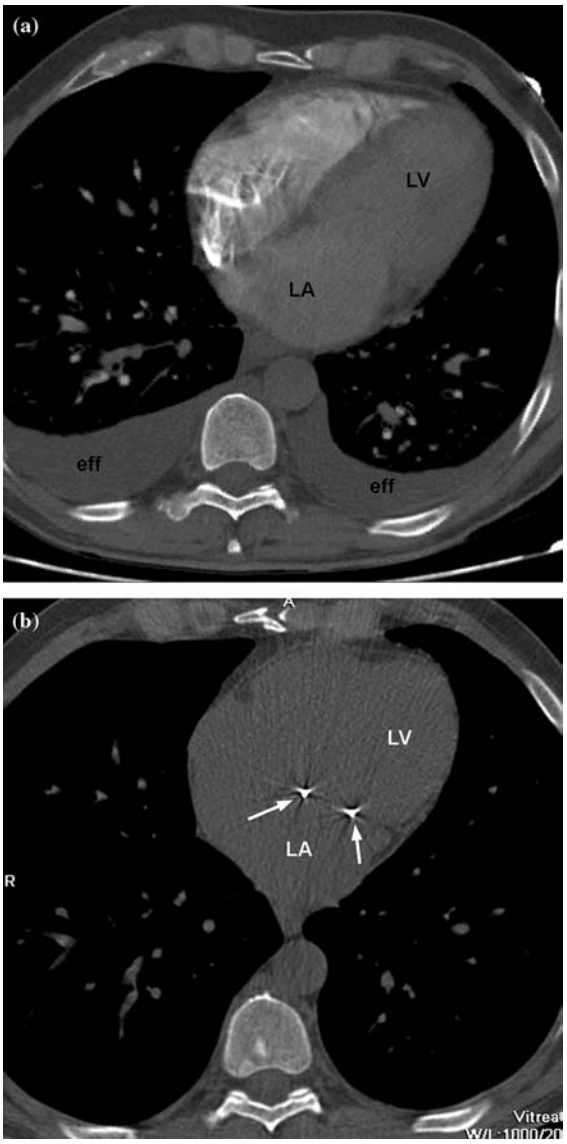

Figure 8. A 54 year old man with a 1 week history of increasing shortness of breath. (a) Contrast-enhanced, non-ECG-gated multidetector CT examination to exclude pulmonary embolism. Left (LA) atrial and ventricular (LV) enlargement and bilateral pleural effusions (eff) characterize his diminished left ventricular function. (b) Non-contrast-enhanced, ECG-gated electron beam CT examination obtained 11 months after mitral valve replacement. The width of the mitral orifice is defined by the diameter of the prosthesis (arrows) viewed in profile. Overall heart size, as well as left atrial (LA) and ventricular (LV) size has decreased.

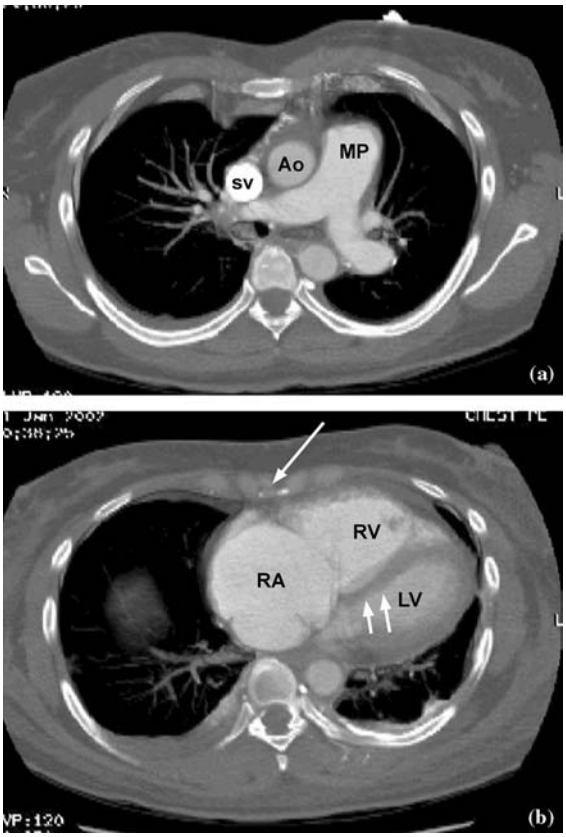

Figure 9. Contrast-enhanced non-ECG-gated multidetector examination of a 43 year old woman with primary pulmonary hypertension, tricuspid regurgitation and right heart failure. (a) Image obtained through the superior vena cava (sv), ascending aorta (Ao), and main pulmonary artery (MP). The MP is greater in caliber than the Ao, indicating that it is dilated. Furthermore, the sv is nearly the size of the Ao, indicating that it, too, is dilated. (b) The left ventricle (LV) is normal. Right atrial (RA) and ventricular (RV) dilatation is characterized by clockwise rotation of the heart toward the left. Notice how the hypertrophied RV free wall is to the left of the sternum (long arrow), and that the interventricular septum is flat (short arrows).

the valve disease. Pulmonary hyperaeration indicates obstructive lung disease as the cause of the pulmonary hypertension and tricuspid valve dysfunction. Left heart dilatation, or regional left ventricular dysfunction indicates left heart disease as the etiology of the right heart dysfunction. Left atrial calcification or interstitial lung change with a normal appearing left ventricle indicates mitral stenosis causing right-sided changes.

Conclusion

Non-invasive techniques have allowed us to diagnose valvular heart disease earlier, and follow asymptomatic patients, increasing our understanding of the natural history valvular heart disease, and improving our ability to time appropriate intervention. The association between calcification and valvular heart disease calls out for a method for precise and reproducible quantitation of calcium deposits. EBCT and MDCT allows us to do just that. In addition to their ability to demonstrate morphologic changes seen in these patients, they allow us to estimate valve calcium concentration, potentially a means of following the natural history of these patients. The proliferation of fast scanners will allow us to study more patients, and thus improve their care, and resuce their morbitity and mortality from valvular heart disease.

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