The Role of Computed Tomography in the Management of Cardiac and Coronary Artery Disease

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Computed tomography (CT) has become an increasingly important tool in the diagnosis and management of cardiac and coronary artery disease (CAD). CT calcium scoring procedures are able to rapidly assess calcium burdens in the coronary arteries. This procedure is non-invasive, inexpensive, quick, and provides an entry-level predictor of coronary artery disease. CT can also define coronary artery anatomy using intravenous iodinated contrast with a coronary artery computed tomography (CCTA) scan. CCTA is the only other imaging modality, besides cardiac catheterization, that can rapidly visualize and evaluate the major epicardial vessels for CAD. A CCTA evaluates disease without having to make arterial punctures, while providing immediate results. Cardiac CT can also evaluate structural heart disease and is essential in the planning of transcutaneous aortic valve replacement (TAVR). This overview will discuss the important role of CT in the diagnosis and management of coronary artery and cardiac disease, as well as basic imaging techniques and procedural considerations.

Calcium Scoring

A CT calcium scoring scan is a screening test that produces images to detect and measure calcium-containing plaque in the coronary arteries. Coronary calcium is a marker for atherosclerosis and calcium deposits can appear years before symptomatic CAD. The presence and the amount of calcium detected in a coronary artery by CT calcium scoring is a predictor of atherosclerosic disease.

CT calcium scoring is based on a weighted calculation of densities, or calcification, using the Agatston scoring algorithm (Table 1). This algorithm grades plaque burdens on a scoring system of 0 to 400+, with higher scores equaling higher plaque burdens and higher probabilities of CAD. A CT threshold score of 130 Hounsfield units[1] (HU) is selected and a coronary score for the left main coronary artery, left anterior descending coronary artery, circumflex coronary artery, and the right coronary artery is obtained. The scanner software identifies calcium in the 4 major coronary arteries and their branches, and assigns a score based on the extent of calcium and density of detects within the coronary arteries (Figure 1).

Procedural preparation involves the placement of 4 electrocardiogram (ECG) leads positioned in the left and right subclavian area, and bilateral leads positioned inferiorly below the ribs. The lead placement minimizes registration artifact on the images. The CT calcium scoring scan utilizes low-dose ionizing radiation, but does not require intravenous contrast or drugs such as beta blockers. These scans are rapidly performed and interpreted.

A calcium scoring exam may be indicated for patients who are asymptomatic and to rule out the possibility of CAD. Candidates for standalone CT calcium scoring include those with a family history of CAD. Other indications include obesity, a history of tobacco use, hyperlipidemia, hypertension, or diabetes.[2] The CT calcium scoring scan is a screening test or life scan, and does not usually lead to an invasive procedure or cardiac catheterization. However, it will guide physicians with medical management issues such as lifestyle changes, diet modification, or preventative medications.

The main limitations of CT calcium scoring are that it is an out-of-pocket expense unless it is authorized by insurance as part of a CCTA exam. There is also potential for incidental findings due to the display field of view that is used to obtain the scan (Figure 2). Since the display field of view covers the heart and much of the mediastinum, incidental extra-cardiac findings have been reported that may lead to unnecessary follow-up studies and treatments.[3]

Coronary Artery CTA

The CCTA can rule out CAD with specificity and sensitivity rates up to 95%.[4] The CCTA is indicated

Table 1. The Agatston score and the criteria used to evaluate coronary artery disease (CAD) risk.

Agatston Score	Calcium Present	CAD Probability	Associated Risk of CV Disease	Outcomes
0	None Visible	Less than 5%	Very low	Discuss general guidelines/ prevention of CV disease.
1 - 10	Minimal	Less than 10%	Low	Discuss general guidelines/ prevention of CV disease.
11 - 100	Mild	Mild or minimal stenosis likely	Moderate	Advise regarding risk factors changes and preventative goals. ASA daily.
101 - 400	Moderate	Nonobstructive and obstructive disease highly possible	Relatively high	Establish risk factor changes and preventative goals. Recommend exercise testing. ASA daily.
401 and above	Extensive	Greater than 90%	Very high	Instruct regarding risk factor changes and preventative goals. Recommend exercise/imaging testing. ASA daily.

Data taken from Neves et al[1] and Adelhoefer et al[2]. *CAD, coronary artery disease; CV, cardiovascular; ASA, aspirin*

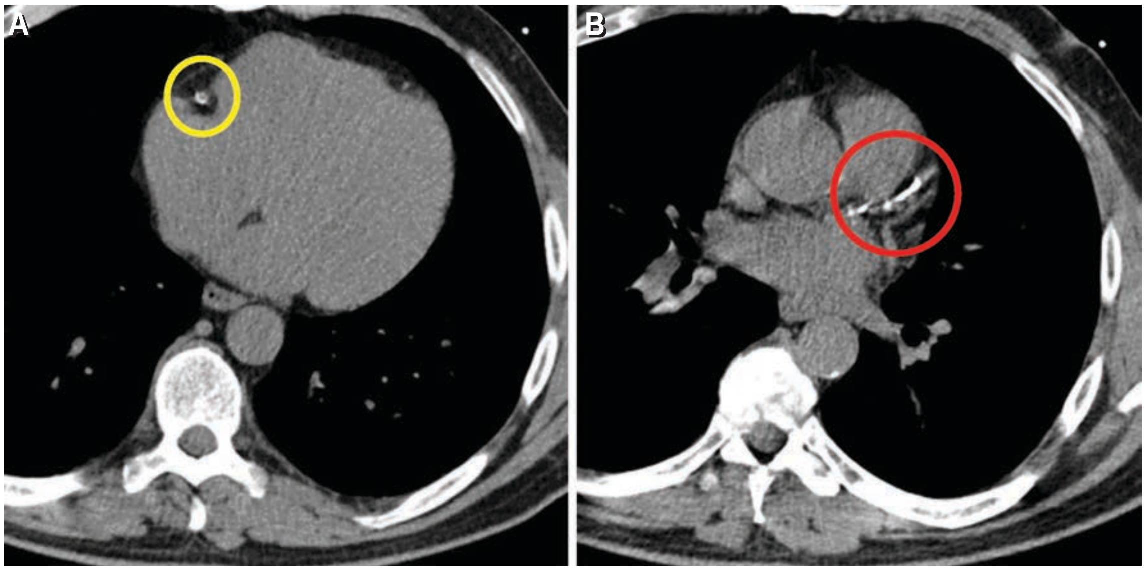

Figure 1. Calcium deposits are easily visualized on an unenhanced computed tomography (CT) calcium scoring in the right coronary artery indicated by the yellow circle (left image). The left main and left anterior descending artery are heavily calcified, indicated by the red circle (right image).

for the evaluation and CAD in the major epicardial vessels. Clinical indications include:

1. Low to intermediate risk for CAD, including patients who have chest pain and normal, non-diagnostic or unclear lab and ECG results;
2. Unclear or inconclusive stress test results;
3. Non-acute chest pain, and new or worsening symptoms with a previous normal stress test result;
4. New-onset heart failure with reduced heart function and low or medium risk for CAD;
5. Intermediate risk of CAD before noncoronary cardiac surgery;
6. The evaluation of coronary artery bypass grafts.[5-7]

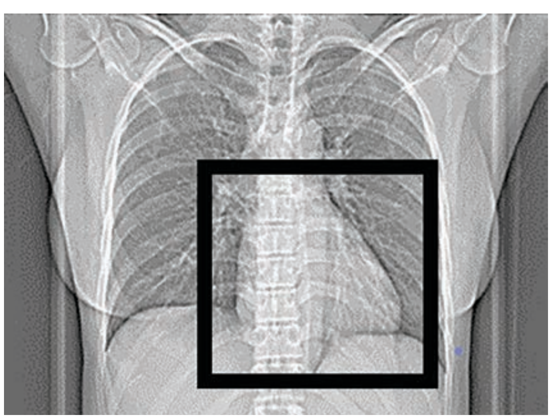

Figure 2. An initial CT scout view or topogram while establishing the black square area covering the field of view and the extent of scan for heart imaging.

For emergency medicine, a CCTA can perform a triple chest pain rule-out. It evaluates coronary circulation while also visualizing the pulmonary arteries and thoracic aorta with a single scan,[7] helping clinicians rule out CAD, pulmonary embolism, and aortic dissection with one quick diagnostic procedure.

A high-quality CCTA is dependent on numerous factors including display field of view, multi-detector CT (MDCT) scanning, image reconstruction ECG gating, and heart rate control. CCTA also requires the use of a bolus of intravenous (IV) iodinated contrast.

The display field of view needs to include the entire heart in a target zoom of 18 cm to 20 cm. The extent of scan begins at the carina and extends below the apex of the heart in a cranial to caudal scan direction,

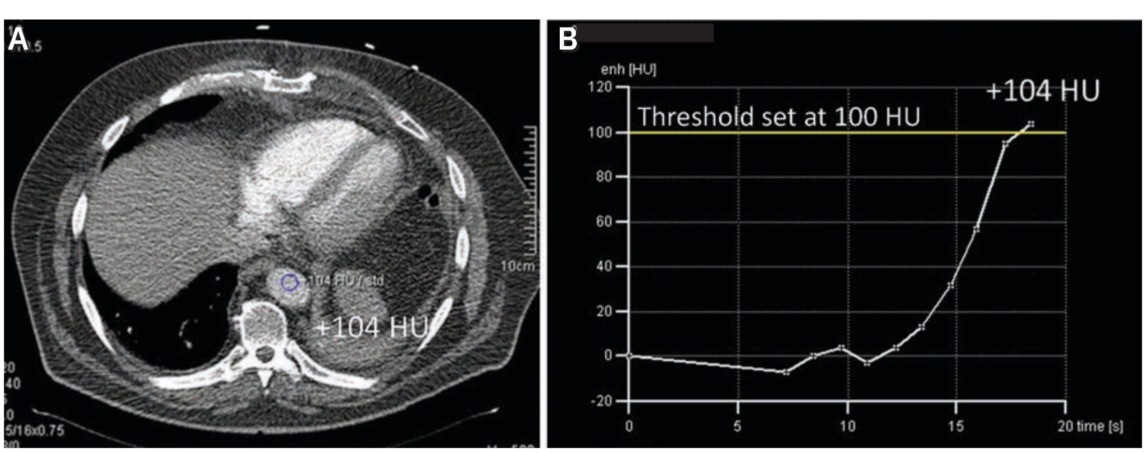

Figure 3. (Left) The bolus tracking technique allowing the density measurement of contrast within the descending aorta once the threshold is achieved for peak IV contrast enhancement and (right) timing of the acquisition during the arterial system.

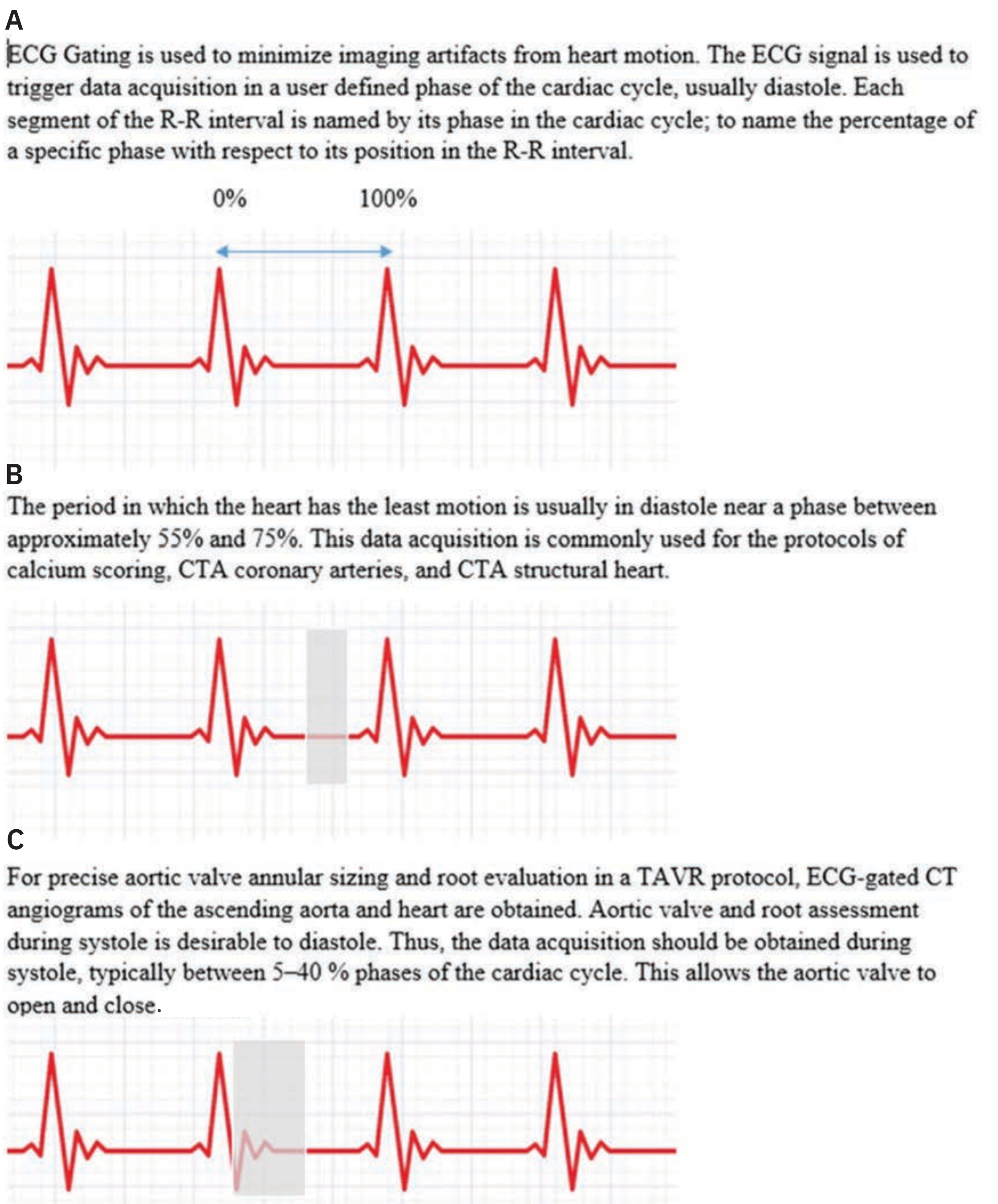

Figure 4. A basic understanding of how gating techniques are used for CT cardiac imaging. (A) demonstrates the R-R interval or percentage of a cardiac cycle. (B) shows the CT data acquisition for a coronary artery calcium scan, CTA coronary, or structural heart imaging. (C) indicates CT data acquisition gating techniques for transcatheter aortic valve replacement (TAVR) protocol.

ECGs and information from the authors and modified from Rybicki FJ. Protocol fundamentals for coronary computed tomography angiography. *US Cardiology.* 2005;2(1):119-121. https://doi.org/10.15420/usc.2005.2.1.119

ensuring that the entire heart is imaged on the scan.

MDCT scanning, considered to be the gold standard for CCTA imaging, must utilize a 128 and above detector scanning unit for superior imaging. A 128 and above detector scanning unit means a CT unit has the capability to accommodate 128 images per gantry revolution (nearly one quarter-second duration). The collimation acquisition is around 0.6 mm, allowing very thin slices to reconstruct.

CCTA uses approximately 75 mLs of IV contrast with normal saline to image the coronary arteries and adjacent structures. An antecubital IV of 20 gauge or larger is recommended to deliver the bolus. The use of a bolus tracking technique is utilized to optimize peak enhancement of the IV contrast to the vascular target structure. An automatic software enables the triggering acquisition of the CT scan at the optimal phase of the contrast enhancement, creating improved image quality and higher reliability, and added confidence for the CT technologist. Acquisition is accomplished while the CT scan tracks the IV contrast within the blood at a predefined density, or threshold (100 HU), via the area's region of interest (Figure 3). Once the threshold is reached, the scan is acquired.

ECG gating is an acquisition technique that optimizes a scan by producing data at a defined phase of the cardiac cycle (for CCTA, this is usually in diastole). ECG gating reduces motion artifacts and misregistration errors. Diastole encompasses the time period during which the myocardium loses its ability to generate force and shorten, and returns to resting force and length. The period in which the heart has the least motion is usually in diastole, near a phase between 55% and 75%. The diastolic phase of ventricular motion also correlates with maximum coronary artery perfusion (Figure 4).

Heart rate control is essential for a successful procedure and the goal is having a target heart rate of 60 beats per minute or less. The patients should be NPO and not consume caffeine for 24 hours pre procedure. For patients with tachycardia or high normal heart rates, IV or PO beta blockers may be used to reduce the heart rate before the scan. Additionally, sublingual nitroglycerin is given prior to IV contrast administration for rapid vasodilation of the main coronary vessels, which improves diagnostic imaging.

Contraindications of CCTA include hemodynamic instability, decompensated heart failure, acute myocardial infarction, previous coronary artery stenting, and severe coronary artery calcification, which can overcall CAD.[4,8] Renal impairment is another potential contraindication to CCTA. A skilled interventional cardiologist can perform a diagnostic catheterization with as little as 20 mLs of contrast. For patients with kidney disease, the possibility for needing a cardiac cath after a CT scan, meaning a higher dose of contrast, may make cardiac catheterization the more appropriate choice of imaging. Other procedural limitations include arrhythmia such as atrial fibrillation, and tachycardias, which can present significant imaging challenges. Patients who have reactive airway disease and rapid heart rates may not be candidates if they cannot tolerate beta blockers to reduce their heart rate. However, the arteries may still be imaged and interpreted by experienced operators who use advanced data acquisitions, state-of-the-art CT scanners, and software modifications to meet these challenges.

As CCTA imaging reliability continues to increase, the scans may eventually limit the indications for coronary artery angiography to cases that require surgical intervention or percutaneous coronary intervention. In recent clinical studies, the sensitivity and specificity of CCTA is as high as 95%.[4,10,11]

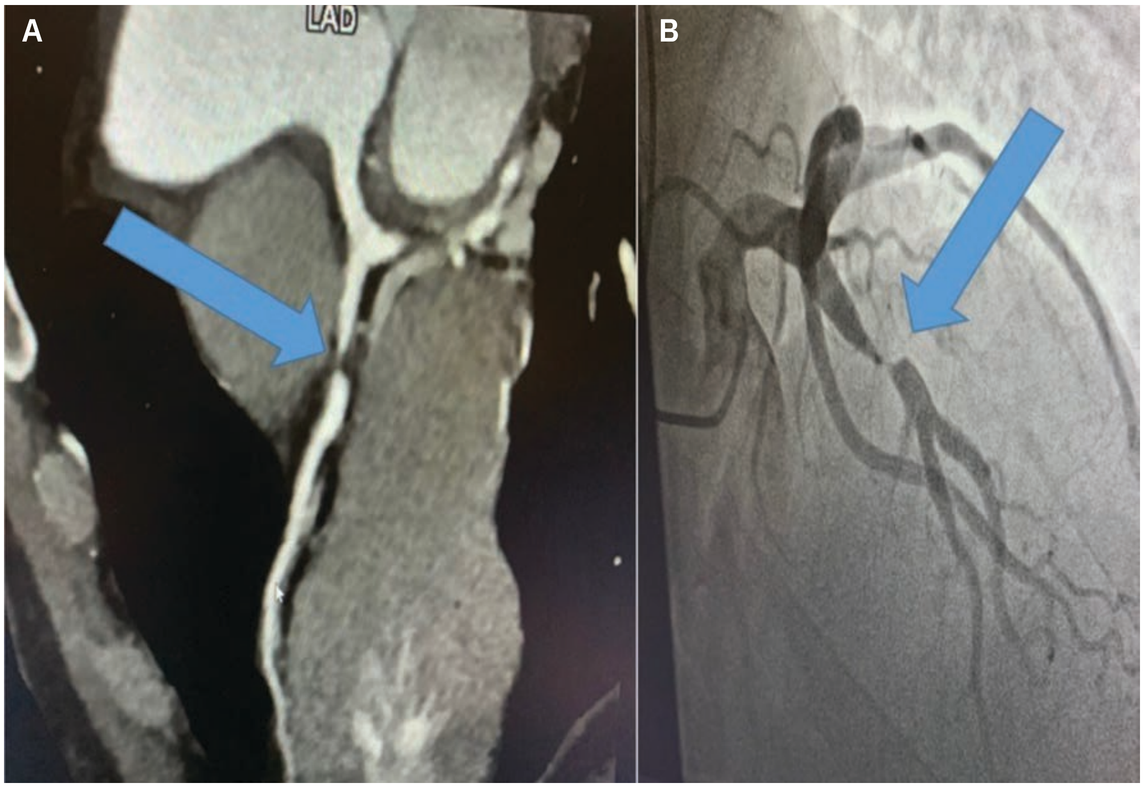

Figure 5. The blue arrows demonstrate a mid left anterior descending stenosis via CT and angiography that was successfully stented.

While conventional coronary angiography is considered the gold standard in the assessment of coronary arteries, advances in CCTA have made it an important tool in diagnosing CAD (Figure 5). Continued advancement in CT technology and the development of a new CAD Reporting and Data System (CAD-RADS) have increased dependence on CT coronary angiography as a reliable imaging technique for CAD assessment.[9] As CCTA imaging reliability continues to increase, the scans may eventually limit the indications for coronary artery angiography to cases that require surgical intervention or percutaneous coronary intervention (PCI). In recent clinical studies, the sensitivity and specificity of CCTA is as high as 95%.[4,10,11]

TAVR Evaluation

As transcatheter aortic valve replacement has become a frontline treatment for aortic valve stenosis (AS), CT has become the cornerstone imaging modality for the pre-TAVR workup. CT provides 3-dimensional images of the heart, and offers a rapid and complete evaluation of aortic valve morphology and size (Figure 6). CT also evaluates the ascending aorta, coronary arteries, peripheral access vessels, and prognostic factors (Figure 7). Additionally, it provides preprocedural coplanar fluoroscopic angle prediction to obtain complete assessment of the patient. The most relevant dimension in preprocedural planning of TAVR is the aortic annulus, which can determine the choice of prosthesis size.[12]

The TAVR protocol usually starts with an unenhanced CT scan of the chest, abdomen, and pelvis. Preparations are the same as for the CT calcium scoring scan and CCTA protocols, including establishing a controlled heart rhythm, ECG gating techniques, IV access, and the MDCT unit (128 slice or greater). Acquiring the unenhanced scans establishes the location of the aortic root or valve. Unenhanced scans also serve as a baseline for any existing hyper-dense findings, helping to define questionable areas around any densities on the enhanced scans.

Once the location of the aortic root is identified on the unenhanced scan by the CT technologist, the second enhanced scan starts with a 10 mm scan coverage acquired during the initial IV contrast bolus technique, allowing for optimal peak enhancement to the aortic valve. A third scan is initiated, serving as the final portion of the CTA of the chest, abdomen, and pelvis, or whole-body scan. The whole-body CTA evaluates the entire aorta, ilio-femoral arteries, and coronary arteries. The whole-body study guides the physician in obtaining vascular access, as it can visualize the tortuosity of the aorta and the vascular access routes (iliofemoral, subclavian, trans-apical, or direct aorta). CTA is also essential to identify patients with increased anatomical risk for coronary artery occlusion in valve-in-valve (ViV) procedures (Figure 8). CTA is also very useful in the evaluation of late complications, such as perivalvular leaks, thrombosis, and valve displacement.[12,13]

Structural/Functional Heart CT

A gated cardiac CTA (structural/functional heart) is an increasingly viable imaging option for left atrial appendage occlusion, congenital heart disease, atrial or ventricular septal defects (Figure 9), valvular disease and prosthetic valvular dysfunction, cardiomyopathies, or cardiac masses such as myxomas.[14,15] To perform a structural/functional heart scan, the CCTA and CT cardiac scoring scan protocols are used. The difference is the injection timing and setup with

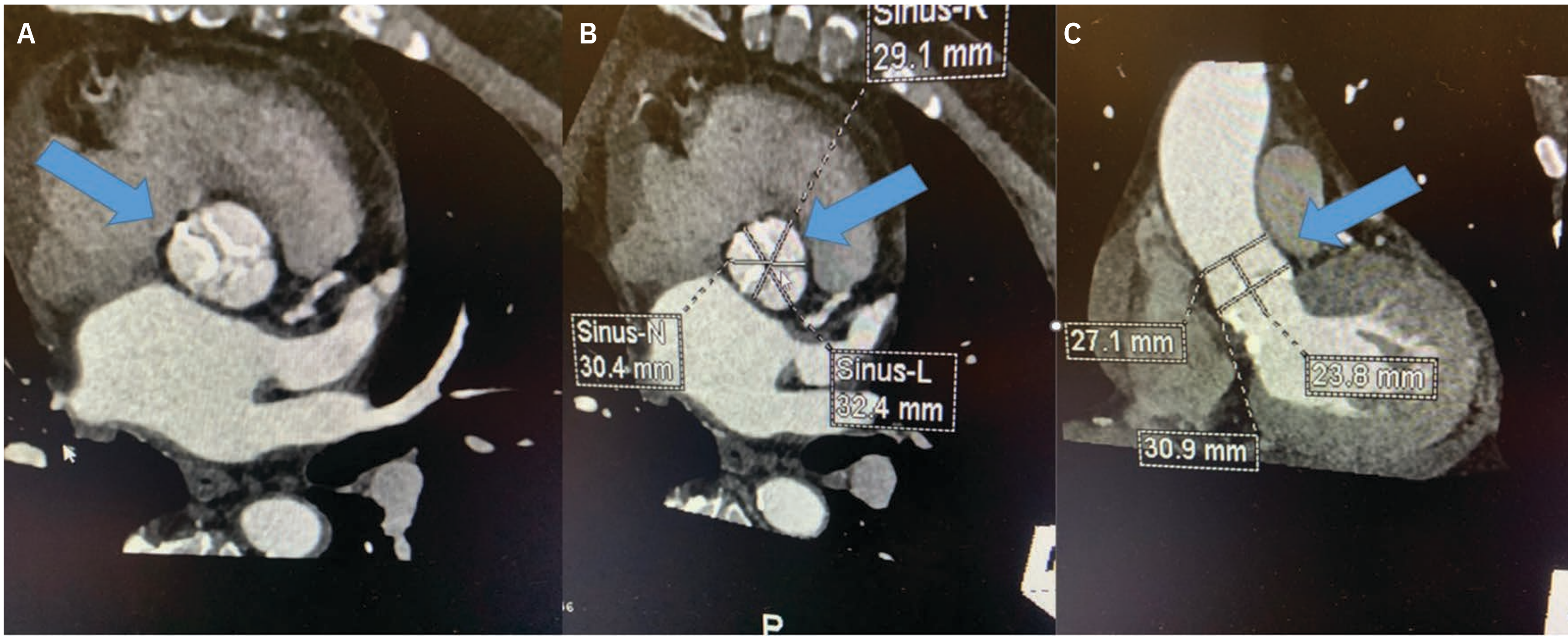

Figure 6. CT measurements taken as part of a pre-TAVR workup to assess the aortic valve.

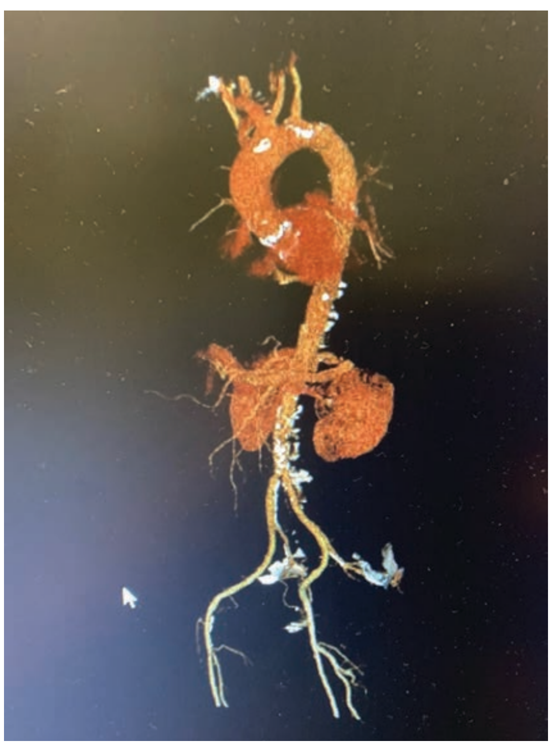

Figure 7. CTA demonstrating the entire aorta and iliofemoral arteries as part of the pre-TAVR workup.

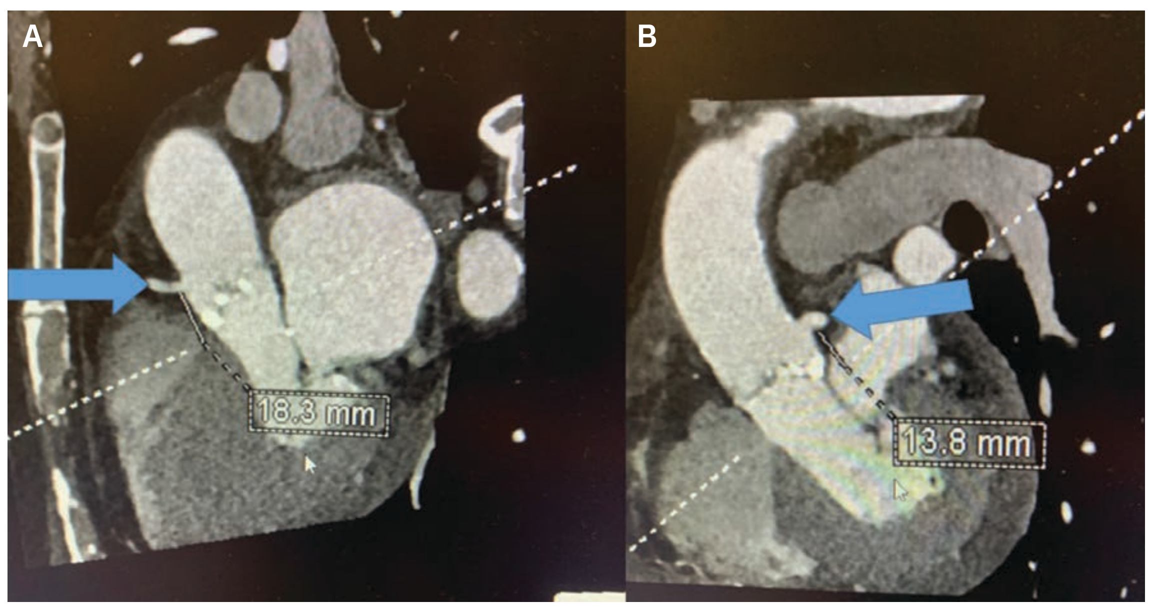

Figure 8. (Left) The right coronary artery ostium and (right) the left main ostia as part of a pre-TAVR workup.

the dual-head syringe power injector. The objective is to allow segmentation and analysis of all cardiac chambers, as well as the coronary artery visualization. Functional or structural cardiac imaging allows for visualization of any atrial or ventricular septal defeats, as well as any cardiac masses, tumors, metastatic disease, thrombi, and vegetation.

A baseline CT calcium score starts the procedure. A split bolus contrast injection technique is then utilized to obtain images. There are a total of 4 injection phases:

- 1st phase: 25 ccs normal saline to test the patency of the IV site;
- 2nd phase: 50ccs IV contrast for enhancement of the left side of the heart;
- 3rd phase: 50ccs IVC 40/60 saline-to-contrast medium mixture for enhancement of the right side of the heart;
- 4th phase: normal saline to chase and clear the rest of the IV contrast in the brachiocephalic veins and SVC.

During CCTA acquisition, a total of 100 mL iodinated contrast is injected using the split bolus technique.

The goal of this protocol is to enhance both sides of the heart equally. The motion of the left and right coronary arterial system differs in most patients, with right coronary artery (RCA) motion being greater. The split bolus IV contrast technique, specifically the 40:60 normal saline-to-contrast mix, minimizes artifact from high concentrations of IV contrast on the right side of the heart, while the first phase focuses on the right side. The advantage to this protocol is how it maintains enhancement on the left side of the heart and the coronary arteries, while improving the right side for IV contrast opacification.

Figure 9. An atrial septal defect (yellow circle).

Conclusion

Cardiac and coronary artery CT is increasingly important in the management and detection of coronary artery and structural heart disease. It also has the ability for a triple rule-out of CAD, pulmonary embolism, and aortic dissection. Advances in imaging techniques and operator experience make CT increasingly reliable, and as the technology continues to improve, CCTA should become more prominent as a diagnostic alternative to cardiac catheterization. CT has become the core imaging modality for planning TAVR procedures, and is extremely important for diagnosing post-TAVR complications. It is also extremely valuable in assessing valvular dysfunction in other prosthetic valves, planning left atrial appendage occlusion, and interpreting structural heart disease. CT is an important tool in the diagnosis of coronary artery disease, valvular heart disease, and structural heart disease, and its value only continues to grow. ■

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