Assessing Anatomy for Left Atrial Appendage Closure

The roles of TEE and CTA in anatomic assessment and device selection for LAA closure.

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Left atrial appendage (LAA) closure is now a commercially available alternative means of thromboprophylaxis in atrial fibrillation patients who are not ideal candidates for oral anticoagulation. Although the rate of major procedural complications has significantly improved from 8.7% in the initial prospective study (PROTECT AF) to 4.2% in PREVAIL, there is still a strong incentive to minimize the degree of catheter manipulation in the left atrium and to accurately size occluder devices, thus decreasing opportunities for complications.[1,2] Currently, the state-of-the-art imaging modality to evaluate the LAA is transesophageal echocardiography (TEE), the gold standard for anatomic characterization and procedural guidance throughout all of the landmark prospective trials.[3]

TEE USAGE AND TECHNICAL TIPS

TEE provides high-resolution multiplanar imaging that is especially suitable for evaluating soft tissue. Characterization of the atrial appendage using TEE is performed using four main viewing angles: 0°, 45°, 90°, and 135°.[4] From these views, maximal LAA length and width are ascertained, and a device is chosen based on the manufacturer's sizing guide in the instructions for use.[4] The appendage must be at least as deep as the size of the measured ostia to ensure safe implantation, otherwise, the patient will be ineligible. The Watchman device (Boston Scientific Corporation) comes in five sizes (21, 24, 27, 30, and 33 mm), and it is recommended that the selected device achieve 8% to 20% compression. Accurate measurements are important in order to select the appropriate device size based on the maximum LAA diameter. It is generally recommended that preprocedural TEE be performed to ensure anatomic suitability for Watchman implantation and to not bring the patient to the catheterization suite until implantation is relatively ensured, although some centers have chosen to perform anatomic assessment and implantation in the same setting.[5]

During the procedure, TEE is used to reexamine the appendage under general anesthesia. After excluding thrombus and reconfirming measurements, TEE is particularly useful for directing the trajectory of the transseptal puncture. The fossa is punctured posteriorly and inferiorly, which then facilitates an anterior and superior trajectory. TEE can also direct the posterior and inferior trajectory of the transseptal puncture, as well as confirm the coaxial guide trajectory prior to device delivery (Figure 1). Live surveillance of the device deployment is then used to determine appropriate implantation depth and device stability. If the device appears to be properly placed with respect to the LAA ostia, a "tug test" can be performed, and compression is checked by TEE to assess for device stability. The device should be compressed 8% to 20% to follow manufacturer recommendations prior to releasing. In addition to assisting with deployment, TEE can detect complications early in the case. Identification of pericardial effusions and suboptimal device implantation are vital to procedural safety and to avoid complications, such as device embolization.

LIMITATIONS OF TEE

Although TEE is currently the standard for image guidance for LAA occlusion, it is not without its limitations. Most patients are volume depleted for outpatient TEEs, as they must fast for 6 hours prior to the procedure. The LAA size depends on adequate preloading, and hence, preprocedural outpatient TEE

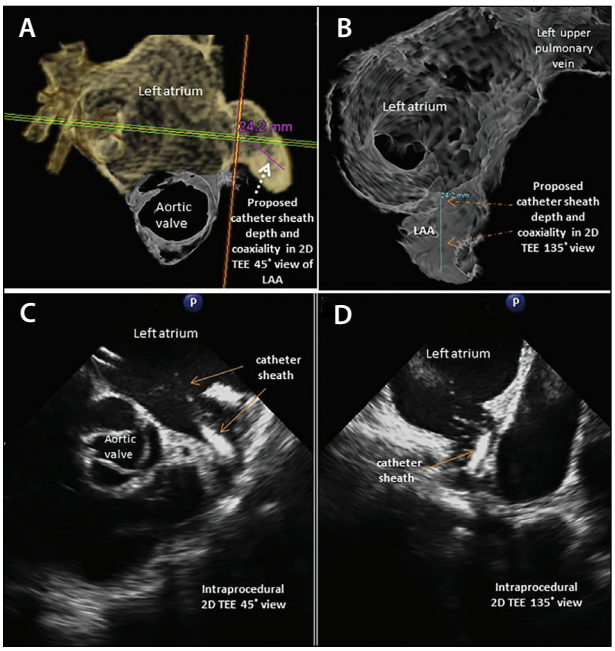


Figure 1. The two most important views for Watchman implantation (the 2D TEE 45° and 135° views) are segmented by CT. The previously identified necessary depth of deployment for the device size chosen is projected with a three-dimensional (3D) straight line into the 3D transparent volume image of the LAA to demonstrate catheter positioning (A, B), as it would appear on the corresponding intraprocedural 2D TEE 45° and 135° views (C, D). In complex anatomies, this helps identify whether the correct delivery sheath catheter tip is coaxial to the appendage. Additionally, the CT-generated delivery catheter positioning on 2D TEE imaging helps guide intraprocedural device and catheter positioning to minimize device "pop out" and peridevice leak (the latter secondary to noncoaxial device delivery). Reprinted with permission from Wang DD, Eng M, Kupsky D, et al. Application of 3-dimensional computed tomographic image guidance to WATCHMAN implantation and impact on early operator learning curve: single-center experience. JACC Cardiovasc Interv. 2016;9:2329–2340.

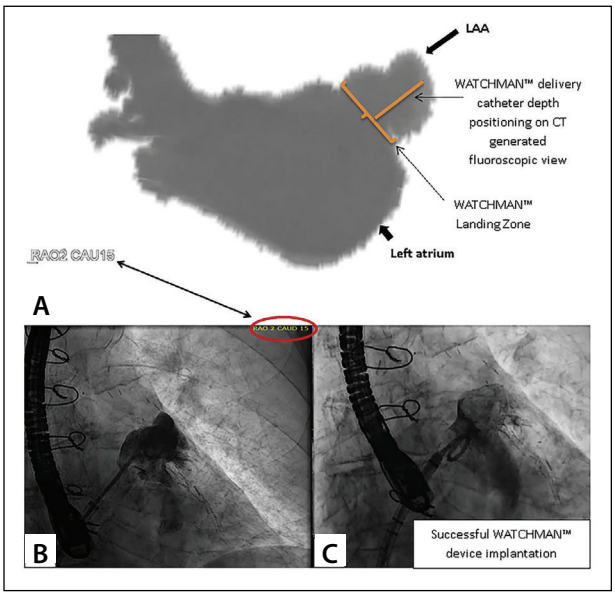


Figure 2. After sizing and depth analysis are completed for the LAA landing zone, the LAA, left atrium, and any pertinent adjacent anatomic landmark structures (transcatheter valves, sternotomy wires, circumflex artery coronary stents, etc.) are segmented and projected into inverted maximum-intensity projection to simulate the intraprocedural LAA angiogram (A). Appropriate C-arm angles are generated and demonstrated on the actual day of a successful procedural implantation with baseline LAA angiography at those angles and final device implantation corresponding to the mockup case plan provided by CT (B, C). Reprinted with permission from Wang DD, Eng M, Kupsky D, et al. Application of 3-dimensional computed tomographic image guidance to WATCHMAN implantation and impact on early operator learning curve: single-center experience. JACC Cardiovasc Interv. 2016;9:2329–2340.

can potentially undersize the true LAA dimensions.[6] Another limitation of TEE may be the underappreciation of LAA contractility, especially in sinus rhythm. The LAA dimensions change during the cardiac cycle, and these changes affect sizing, which may not be appreciated by TEE due to insufficient spatial resolution.[7,8]

APPLICATIONS OF CT

In the search for more comprehensive imaging to provide additional information beyond LAA sizing, CT also has been investigated for evaluating the LAA.[9] CT can be performed with cardiac gating with high-resolution scans, providing physicians with excellent image quality and a volumetric, comprehensive data set (Table 1). CT has been used to evaluate LAA morphology and the high spatial resolution does perform better than TEE; for instance, CT is more sensitive for detecting postimplantation device leaks.[8,10] The promise of a more detailed and comprehensive evaluation of the LAA prompted our center to compare the safety and accuracy of using CT as the primary means for sizing and planning LAA occlusion procedures.

In our pilot study of using CT for LAA occlusion case planning, we learned that CT provides more accurate sizing and improves procedure planning compared to TEE.[11] Using CT, we can better measure the appendage, derive coplanar viewing angles, and if available, perform three-dimensional (3D) printing using the CT data (Table 1). Perhaps the most important function is accurate assessment of the morphology and dimensions of

TABLE 1. CT-BASED LAA IMAGING PROTOCOL

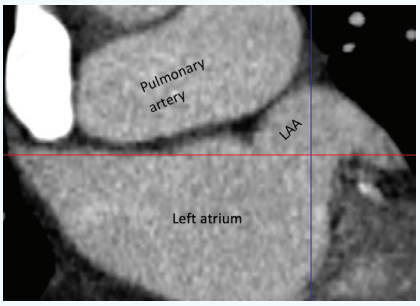
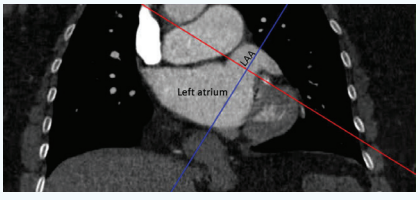
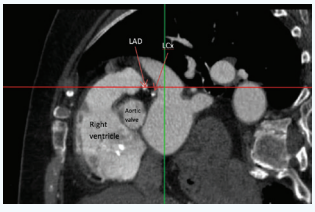
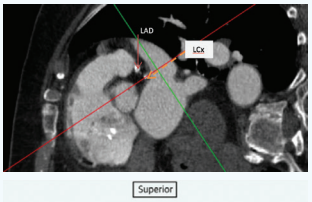
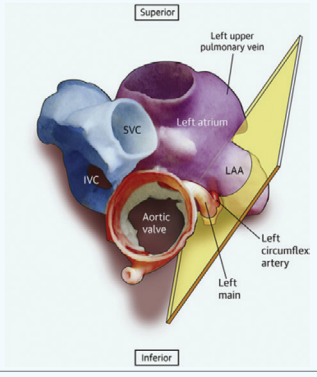
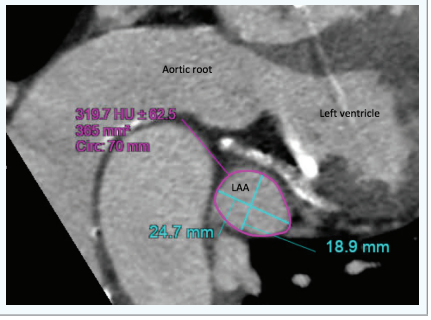
Steps	In-Depth Description	Example Images
Sizing the LAA landing zone	Load the 0%–95% valve series of the LAA into the CT viewer. Identify the phase that corresponds to mid to end LV systolic filling that corresponds best to maximal LAA end-diastolic filling. In the coronal cross-sections, place the crosshairs on the LAA.	
	In a curved multiplanar reformat plane, within the coronal window, double-oblique the sagittal crosshairs (blue) to the direction of the main lobe of the LAA.	
	In the sagittal window, within a curved multiplanar reformat plane, advance the crosshairs to the level of the proximal LCX artery takeoff from the LAD. Then, double-oblique the coronal crosshairs (green) to the direction of the main lobe of the LAA (commonly runs parallel to the course of the LAD).	  
	On the axial cross-sections, measure the maximal and minimal diameters, and circumference of the LAA landing zone.	

TABLE 1. CT-BASED LAA IMAGING PROTOCOL (CONTINUED)

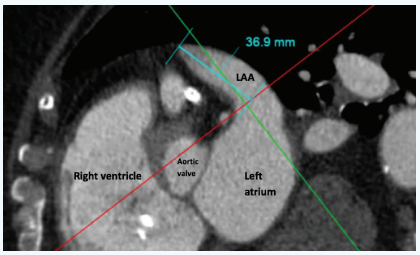
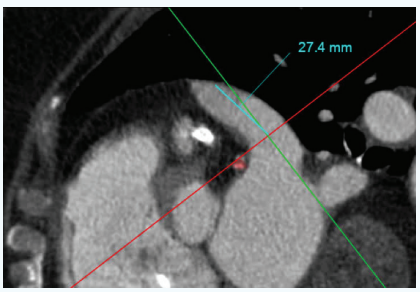
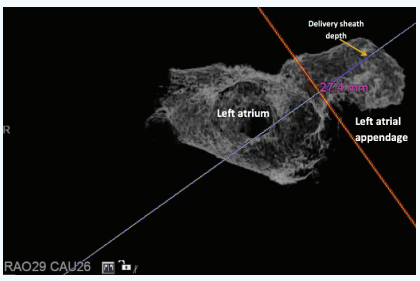
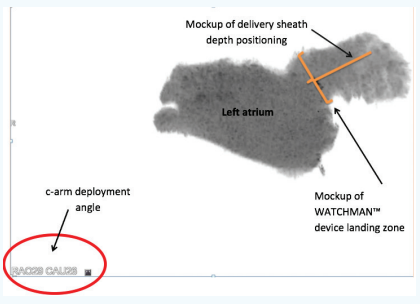
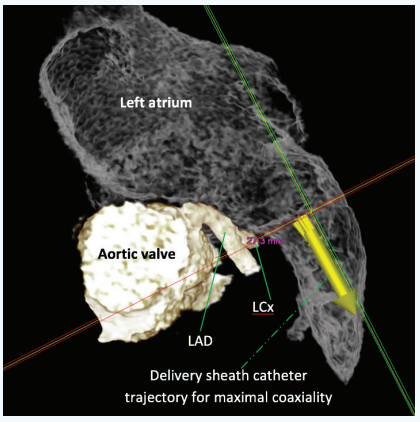
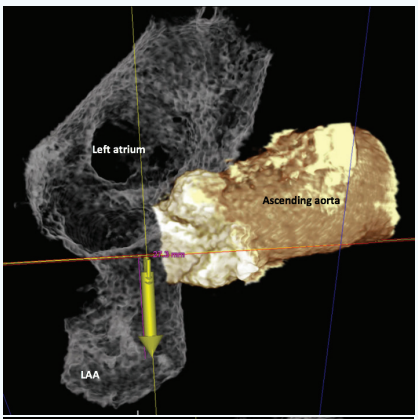
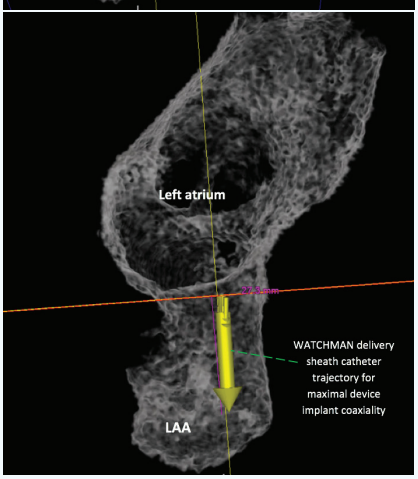
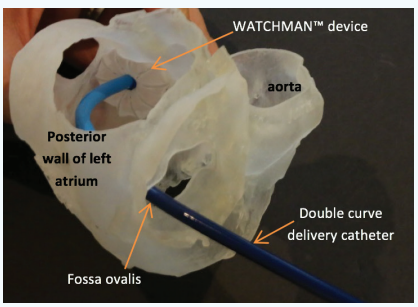
Steps	In-Depth Description	Example Images
Identifying the maximal length to the LAA landing zone to distal tip of the main lobe of the LAA	Identify the maximal length or depth of the LAA from the landing zone to the distal LAA tip in the sagittal and coronal views and record the largest value. (Scroll in and out of the identified view to ensure maximal length is accounted for.)	
Generating the length of the Watchman delivery sheath	Adjust the length measurement to equal the maximal width of the Watchman device selected (per the sizing guidelines from the Watchman IFU). In this patient, a 24.7-mm maximal width diameter corresponds to selection of a 27-mm Watchman device and hence delivery sheath depth of ~27 mm (± 0.5 mm to account for distal delivery tip plastic tricut length and presence or absence of LAA pedunculations protruding into the site of catheter positioning).	
C-arm angles	Segment the LAA, left atrium, into a transparent 3D volume image. In the 3D window, align the axial (red) and sagittal (blue) planes to intersect perpendicular to each other. Show the delivery sheath length in the 3D image (pink line).	
Implanter case plan	Apply inverted MIP to the 3D volume to project the 3D image in a black-and-white radiographic simulation. Load the image screenshot into Microsoft PowerPoint, apply "Insert Art Tool," and overlay the crosshairs with a bracket and line (over the demarcated delivery sheath) to simulate the Watchman device landing zone and delivery sheath depth positioning.	
Interventional imaging case plan (TEE 45° view)	Segment the aortic annulus, proximal LAD, and LCX into the 3D volume. Adjust the image to bring the aortic valve centered and anterior. Adjust the axial (red) and coronal (green) crosshairs to intersect perpendicular to each other. The yellow arrow depicts delivery sheath positioning when imaging in the 2D TEE midesophageal short-axis view of the aortic valve.	

TABLE 1. CT-BASED LAA IMAGING PROTOCOL (CONTINUED)

Steps	In-Depth Description	Example Images
TEE 135° view	Rotate the 3D image along the sagittal plane (red crosshairs) until the aorta is at 3 o'clock and anterior to the LAA. Remove the aortic root from the 3D volume. With the LAA pointing toward 6 o'clock, the yellow arrow depicts the delivery catheter and sheath tip position for maximal catheter coaxiality to optimize Watchman implantation. The sagittal plane (red crosshairs) now depicts the landing zone to be shown by 2D TEE in the 135° view.	 
3D printout assisted type of delivery catheter (single, anterior, double curve) selection	3D printouts of patient's specific left atrial, LAA anatomy were generated to assist in bench-test selection of catheter curvature for device implantation.	

Abbreviations: 2D, two-dimensional; 3D, three-dimensional; IFU, instructions for use; LAA, left atrial appendage; LAD, left anterior descending coronary artery; LCX, left circumflex coronary artery; LV, left ventricular; MIP, maximum-intensity projection; TEE, transesophageal echocardiography.
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the appendage, as CT better appreciates the maximal dimension due to sampling errors made with TEE. Our retrospective series concluded that TEE undersizes the maximal width of the LAA by 2.7 ± 2.2 mm and the length by 4.0 ± 5.8 mm. The ramifications of undersizing are significant; by two-dimensional (2D) TEE maximal width, 62.3% (33/53) of the patients would have received the incorrect initial device and required upsizing to a larger device size intraprocedurally. If not for CT imaging, 12 of 53 patients would have been inappropriately excluded from Watchman implantation either due to width (3/53) or length (9/53)

underestimation.[11] Multiple device exchanges in the left atrium may increase procedural complications, such as air embolism or catheter-related perforation.

CT imaging also allows the acquisition of additional information via a coplanar viewing angle (Figures 1 and 2). Unlike calcified aortic valves and transcatheter aortic valve replacement, there are no radiographic markers to help delineate the coplanar view.[12] Usually, when performing angiography, imaging angles are changed to minimize foreshortening and overlap of other angiographically overlapped structures, most notably in coronary angiography. However, the atrial appendage is entirely a soft tissue structure, and unfortunately, the angiographic projections that minimize foreshortening of the appendage length may not match the coplanar angle for the ostium of the appendage.[11] In a procedure where minimizing the number of device exchanges may help prevent complications, simplifying the procedure to one catheter, one device, and one deployment should enhance safety. Furthermore, narrowing the number of angiographic projections can minimize contrast and radiation exposure, another quality marker and safety measure in the catheterization lab.

Additional uses of CT data include the creation of physical models that can be used for ex vivo bench testing of device fit and catheter suitability (Table 1). The 3D data from a CT can be exported to computer-aided design software, but the data must be manually manipulated and then sent to a 3D printer for creation of an actual physical model. Using this heart replica, catheters and devices can be fit tested and tried prior to starting a procedure. Therefore, many assumptions about coaxial catheter and accurate device selection can be investigated without manipulation in the body, instead of a dogmatic progression from the same standard guiding catheter and changing catheters after failed attempts.

CT LIMITATIONS

Although there are many advantages to using CT data, its use may not be broadly applicable. For instance, a CTA requires an additional dose of radiation and contrast, which may be harmful or undesirable in some patients. Furthermore, processing the data is laborious, and not all centers may have the resources or infrastructure to manually analyze additional CT data. To go forward an additional step to create 3D models, there is an additional cost and infrastructure challenge that may not be easily met in today's health care environment. Nevertheless, improving how we use advanced imaging data is yet another iterative step in advancing the field of interventional cardiology.

CONCLUSION

TEE will remain the cornerstone of performing complex structural heart procedures, but the role of CT in treating aortic valve disease, mitral valve disease, and now left atrial appendage occlusion is becoming indispensible.[11,13,14] The breadth and complexity of structural heart disease interventions continues to expand, and achieving our goal to continue improving the safety, quality, and success of percutaneous interventions will heavily depend on advanced imaging. A mentor once taught me, "Know what you are seeing, and see what you are doing," which remains a fundamental axiom for performing procedures in the catheterization lab. ■

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