Left Atrial Appendage Tilt-Up-and-Turn-Left Maneuver: A Novel Three-Dimensional Transesophageal Echocardiography Imaging Maneuver to Characterize the Left Atrial Appendage and to Improve Transcatheter Closure Guidance

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INTRODUCTION

Atrial fibrillation (AF) is the most common cardiac arrhythmia worldwide, with both incidence and prevalence on the rise. It is estimated that by 2050, up to 16 million people in the United States alone will experience AF.[1] Prevention of systemic thromboembolism and stroke is the cornerstone of long-term management of AF. Although prevention of thromboembolism is often achieved through the use of oral anticoagulants, these agents may be contraindicated in certain patients because of bleeding risk. Because most thrombi in patients with nonvalvular AF form in the left atrial appendage (LAA), closure of the LAA, either surgically or percutaneously, has emerged as an alternative for stroke prevention in patients with nonvalvular AF who are unable or unwilling to take oral anticoagulants.

Before percutaneous LAA occlusion device implantation, accurate LAA anatomy must be determined to select device type. Improper characterization of LAA shape may lead to incorrect device selection, potentially resulting in paradevice leak or even embolization of the device. Moreover, LAA shape may favor one transcatheter closure device over another. We present a three-dimensional (3D) transesophageal echocardiographic (TEE) method to visualize the LAA shape and to orient the LAA in a way that mirrors the fluoroscopic views used during transcatheter closure. This technique uses light-source manipulation technology and transillumination technology (TrueVue and GlassVue, respectively, Philips Medical Systems) to provide high-definition, photorealistic 3D volume-rendered images of the LAA. Compared with other imaging modalities in which it can be difficult to deduce 3D shape from cross-sectional images, the photorealistic rendering acquired with this method allows quick recognition of 3D shape. Additionally, unlike with other imaging modalities, this TEE method allows orientation of images to resemble fluoroscopic views, facilitating intraprocedural guidance.

VIDEO HIGHLIGHTS

Video 1: A complete step-by-step guide to performing a novel 3D TEE maneuver to image the LAA. This video corresponds to Figure 1 and describes all the steps in generating and orienting the 3D TEE images of the LAA. In this video, we mark the landing zone diameter only to demonstrate the approximate location of the landing zone, not to imply that one should rely on landing zone measurements on 3D imaging. All LAA measurements should be done using two-dimensional TEE.

Video 2: Abbreviated version of step-by-step 3D TEE imaging of LAA. This video corresponds to Figure 2; for clarity it omits steps that involve cropping of tissue surrounding the LAA and transparency changes.

View the video content online at www.cvcasejournal.com.

CASE PRESENTATION

An 86-year-old patient with paroxysmal AF was admitted to the hospital with several episodes of bright red blood per rectum. The patient had a CHA_2DS_2-VASc score of 5 and was taking apixaban 5 mg every 12 hours. On admission, anticoagulation was initially held. Colonoscopy performed during the hospitalization revealed internal hemorrhoids, which were thought to be the source of bleeding. The patient was discharged and referred to a cardiac electrophysiologist for consideration of an LAA occlusion device given gastrointestinal bleeding. Following a discussion of the risks and benefits, the patient chose to move forward with LAA occlusion device placement.

Intraprocedurally, TEE imaging was performed. LAA emptying velocity was normal (41 cm/sec), and there was no spontaneous echocardiographic contrast in the LAA and no LAA thrombus. Three-dimensional images of the LAA were obtained using the TUPLE ("tilt up and turn left") maneuver, which is outlined, step by step, in the following section.

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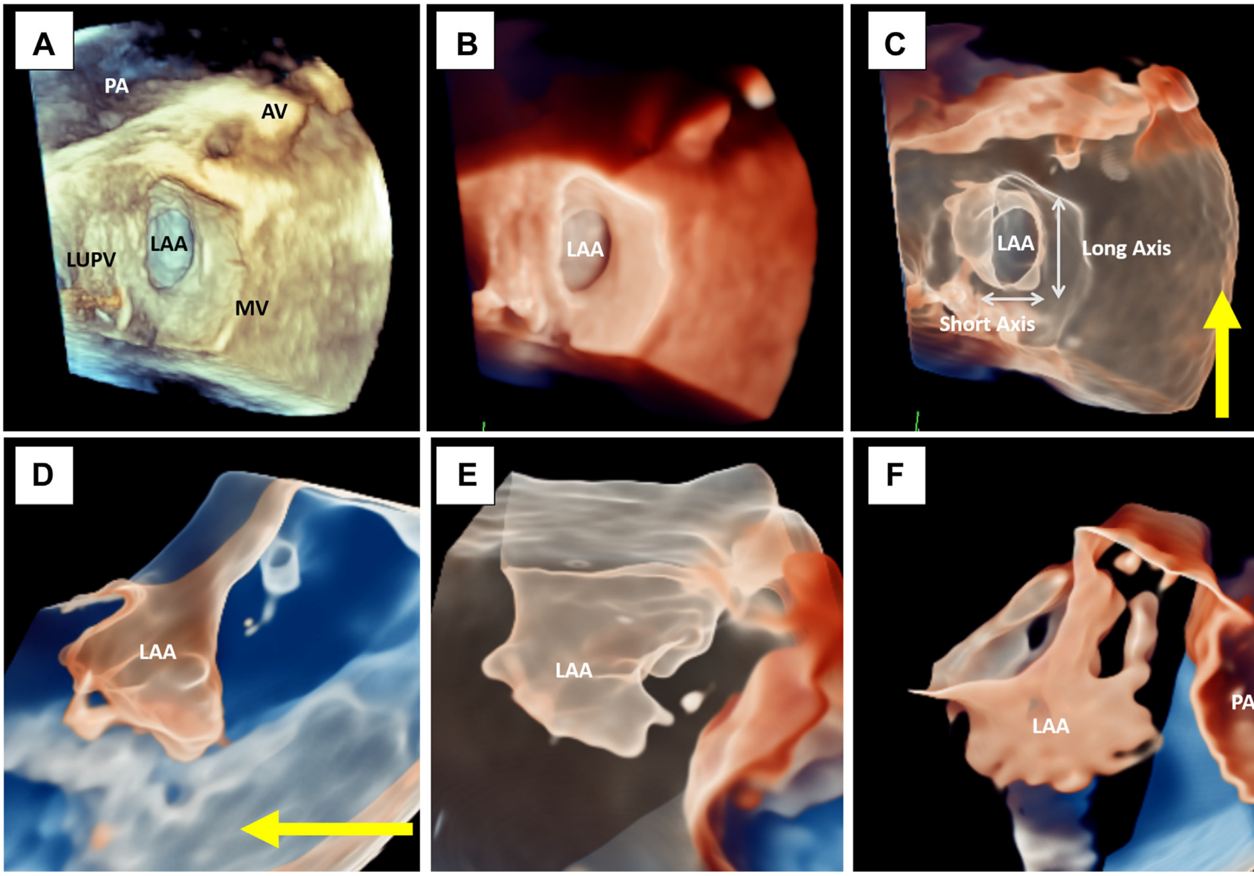

Figure 1 Key steps in volume rending of the LAA. The following steps proceed from a standard en face view of the 3D zoom image of LAA orifice to a volume-rendered image of LAA shape. **(A)** Standard en face view of the LAA orifice seen from the left atrial perspective. **(B)** Light-source manipulation version of **A**. **(C)** Transillumination rendering of the LAA with increased transparency demonstrates the LAA orifice and outlines the walls of the body of the LAA. **(D)** Volume rendering of the LAA demonstrating the short axis of the LAA after tilting the image in **C** upward. **(E)** Volume rendering of the LAA showing the long axis of the LAA after rotating the image in **D** leftward. **(F)** Fully rendered LAA volume after decreasing transparency and increasing image gain. The orientation of this 3D TEE image corresponds to the two-dimensional TEE image at 135°. *AV*, Aortic valve; *LUPV*, left upper pulmonary vein; *MV*, mitral valve; *PA*, pulmonary artery. See Video 1.

INNOVATION

Since the introduction of real-time 3D TEE imaging in 2007, multiple postprocessing technologies to enhance echocardiographic imaging have been developed. Among the most recent innovations are the light-source manipulation and transillumination technologies, which enable anatomic volume rendering and visualization through multiple layers of tissue. These features allow a clear and true rendering of the LAA and its positioning into fluoroscopy-like orientations.

In this report we offer a step-by-step guide on how to reliably obtain high-quality 3D images and anatomically relevant displays during interventional echocardiography. We named this method TUPLE, an acronym for "tilt up and turn left" that refers to two key imaging steps. The TUPLE maneuver refers not only to image acquisition but also to the process of LAA image optimization. We have previously reported a similar method for 3D TEE imaging of the interatrial septum and atrial septal defects.[2]

Obtain a 3D TEE View of the LAA

The first step is to obtain a 3D TEE zoom view of the LAA, and then to orient the image as an en face view of the LAA orifice surrounded by the pulmonary artery at the top of the image, the left upper pulmonary view at the left of the image, and the mitral valve at the right side of the image (Figure 1A, Video 1).

Turn on Light-Source Manipulation and Adjust the Light Source

Once the 3D TEE en face image of LAA is acquired, freeze and scroll through the clip to find the widest LAA orifice size, typically during left ventricular systole and the reservoir phase of the left atrium. Then turn

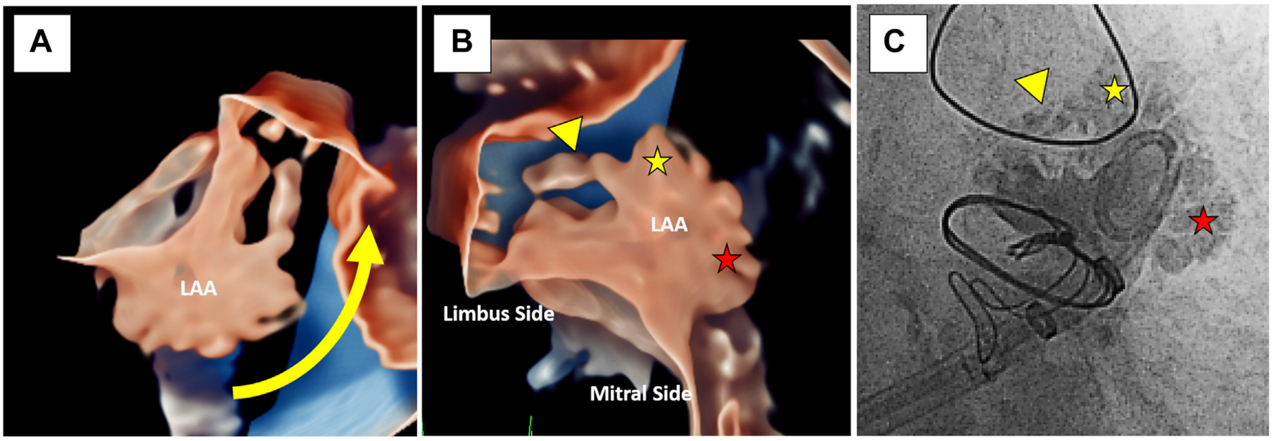

Figure 2 Orienting the 3D TEE LAA rendered volume to correspond to fluoroscopic right anterior oblique (RAO) caudal view. **(A)** Fully rendered LAA volume after decreasing transparency and increasing image gain. The orientation of this 3D TEE image corresponds to the two-dimensional TEE image at 135°. **(B)** This image is obtained by rotating the image in **A** counterclockwise to obtain the view that corresponds to the fluoroscopic RAO caudal view. **(C)** Fluoroscopic RAO caudal view. This view is typically used during transcatheter device closure of the LAA. *Yellow arrowhead* and *stars* in **(B)** align with the same anatomic locations in **(C)**. See Video 2.

on the light-source manipulation feature and adjust the light source (Figure 1B, Video 1).

Change to Transillumination Modality

The next step is to turn to the transillumination feature without transparency for further delineation of the LAA orifice details (Figure 1C, Video 1).

Increase Image Transparency

Next, increase the image transparency until outlines of the body of the LAA are visible (Figure 1C, Video 1).

Tilt the Image Up

Next, tilt the image up so that the LAA orifice faces upward (Figure 1D, Video 1). Crop out excess tissue around the LAA.

Rotate the Image Left

Now rotate the image leftward along the vertical axis of the LAA to reveal the full body of the LAA (Figure 1E, Video 1). Crop out excess tissue around the LAA.

Remove Transparency and Increase Gain

Next, remove the image transparency and add some gain to volume-render the LAA (Figure 1F, Video 1).

Display the 3D Image at the 135° Two-Dimensional TEE Equivalent

Now, orient the LAA image to correspond to the two-dimensional TEE image at 135°. In this orientation, the transverse sinus and pulmonary artery appear on the right side of the image (Figure 1F, Video 1).

Rotate the Image Counterclockwise Along the z Axis to Create a Right Anterior Oblique Caudal Equivalent

Last, rotate the 3D TEE image of the LAA counterclockwise about 90° along the z axis (Figure 2A, Video 2) to obtain the LAA projection that is equivalent to the fluoroscopic right anterior oblique caudal view (Figure 2B, Video 2). The right anterior oblique caudal view is the fluoroscopic view typically used during transcatheter device closure of LAA (Figure 2C, Video 2).

DISCUSSION

This case highlights how the TUPLE maneuver can be routinely used to image the LAA for shape characterization and for intraprocedural guidance during LAA occlusion device placement. Although prior publications have discussed the usefulness and applicability of using the transillumination feature to image the LAA,[3,4] no prior publication has provided a step-by-step guide on exactly how to reliably obtain high-quality images, as we have presented here.

LAA morphology is highly variable and has important implications when it comes to both LAA occlusion device selection and cardioembolic risk.[5,6] Attempts have been undertaken to categorize LAA morphology into four general categories—chicken wing, windsock, cactus, and cauliflower—on the basis of shared traits seen on computed tomography.[5,6] With our described 3D TEE imaging maneuver, the diversity in LAA shape beyond these four categories is evident (Figure 3).

At our institution, this method is used regularly not only to inform device selection but to facilitate intraprocedural guidance. Unlike images acquired using other modalities, the images acquired using this 3D TEE method are able to be positioned in the right anterior oblique caudal view. This provides the interventionalist with a complementary alignment and 3D rendering of LAA size and shape of during the procedure, which facilities closure device placement.

CONCLUSION

The LAA TUPLE maneuver is an innovative way to produce photorealistic 3D images of the LAA using TEE imaging, and to define the exact shape of the LAA. The technique also facilitates orientation

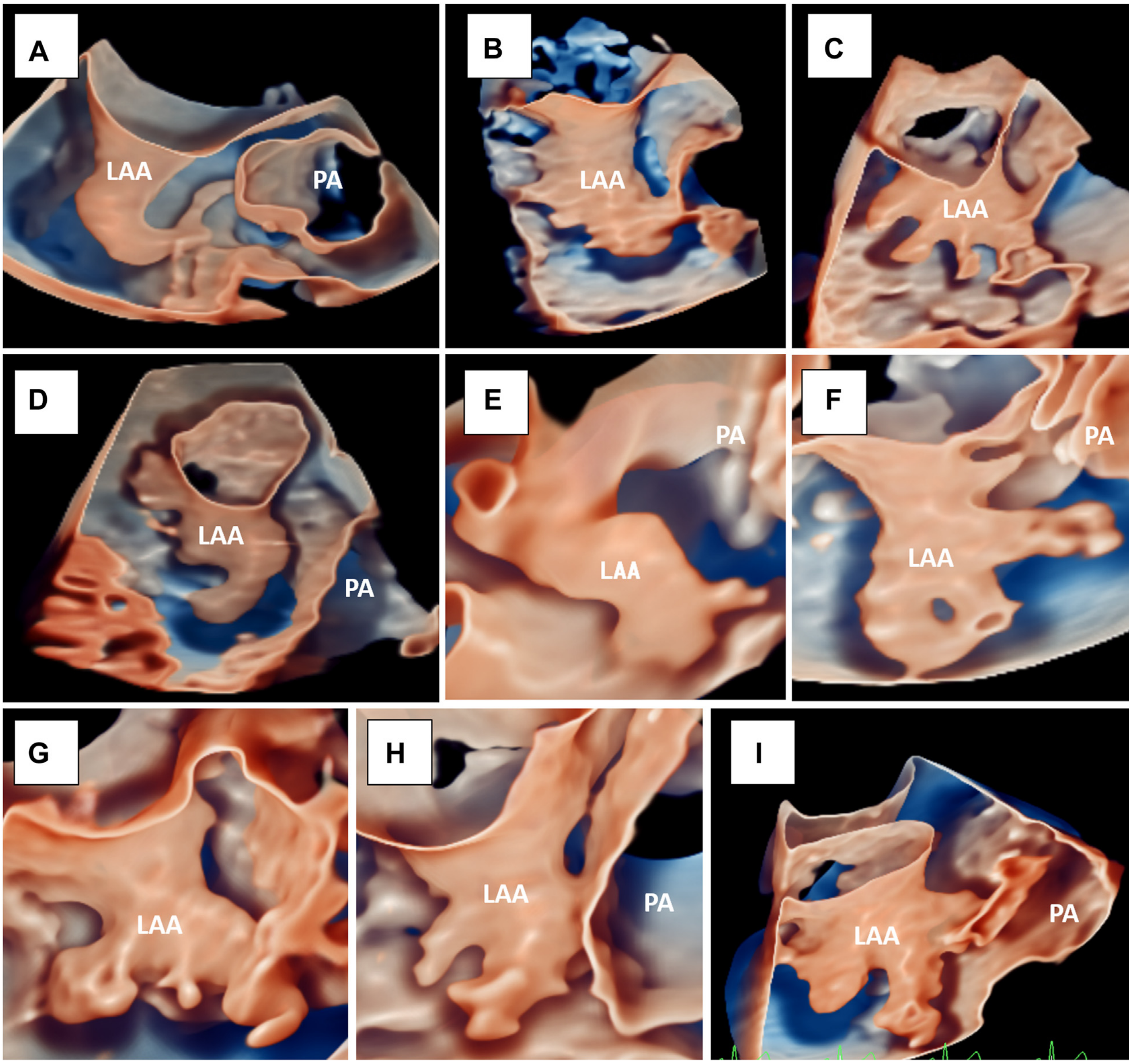

Figure 3 LAA morphologies. Nine distinct LAA shapes demonstrating LAA morphology variability **(A-I)**. *PA*, Pulmonary artery.

of the LAA into fluoroscopically equivalent views for better intraprocedural guidance during percutaneous LAA closure.

ETHICS STATEMENT

The authors declare that the work described has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans.

CONSENT STATEMENT

The authors declare that since this was a non-interventional, retrospective, observational study utilizing de-identified data, informed consent was not required from the patient under IRB exemption status.

FUNDING STATEMENT

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DISCLOSURE STATEMENT

Dr. Vainrib is a consultant for Micro Interventional Devices. Dr. Chinitz is a consultant for Abbott. Dr. Saric is a speakers' bureau member for Abbott, Boston Scientific, Medtronic, and Philips; and is an advisory board member for Siemens.

SUPPLEMENTARY DATA

Supplementary data to this article can be found online at https://doi.org/10.1016/j.case.2023.05.009.

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