Which Cardiac Structure Lies Nearby? Revisiting Two-Dimensional Cross-Sectional Anatomy

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Two-dimensional (2D) transthoracic echocardiography is one of the most used diagnostic tools in clinical cardiology. Similarly, 2D transesophageal echocardiography is considered an indispensable tool for cardiologists and cardiac anesthesiologists worldwide. However, because of their tomographic nature, both techniques display only thin cut planes of a given area of the heart, which are far from representing the "anatomic reality." It is widely accepted that experienced echocardiographers are able to reconstruct mentally a three-dimensional image of any cardiac structure on the basis of their interpretation of multiple tomographic slices. However, this may not be the case with less experienced echocardiographers. In particular, the authors noticed that less experienced echocardiographers are almost totally unaware of which structures lie "nearby" a given 2D tomographic plane, that is, what is adjacent in the elevation plane. In this article, the authors report the use of three-dimensional transesophageal echocardiographic images to discover which structures are located nearby (i.e., "behind" and "in front") the corresponding 2D cross-sections. The authors believe that this novel use of three-dimensional echocardiography is a unique aid to disclose what cannot be seen in a given 2D cross-section, thereby expanding our understanding of 2D echocardiographic anatomy. This may be an effective method to encourage all to "think" in three dimensions, even when they use 2D echocardiography. (J Am Soc Echocardiogr 2018;■:■-■.)

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Two-dimensional (2D) transthoracic echocardiography (2D TTE) appeared in the diagnostic arena several decades ago as the natural evolution of M-mode echocardiography,[1] and today it is probably one of the most used diagnostic tools in clinical cardiology, second only to electrocardiography and chest radiography. Similarly, 2D transesophageal echocardiography (TEE) has also evolved from its initial configuration of a transesophageal probe with a single crystal[2] to monoplane, biplane, and multiplane 2D TEE.[3] Nowadays, multiplanar 2D TEE is an indispensable tool for cardiologists, anesthesiologists, and interventionalists.

However, both 2D TTE and 2D TEE provide real-time images displaying a thin cut plane of a given area of the heart. In the "classic" 2D transesophageal left ventricular outflow view at 120°, for instance, leaflets of the mitral valve are visualized as two subtle lines of valvular tissue, moving during the cardiac cycle and surrounded by a black background. Although this cross-section is very popular, it is far from representing the entire "anatomic reality" of the mitral valve.

The best imaging modality to comprehend the concept of a "thin" slice of tissue is probably the novel fluoroscopy-echocardiography fusion imaging. In this modality, 2D TEE is merged within the fluoroscopic silhouette, and we can appreciate the real thinness of the cross-sectional 2D images[4] (Figure 1, Video 1 available at www.onlinejase.com).

The development of the matrix-array transducer led to the ability to visualize the heart in three dimensions with ultrasound. For the first time, this transducer allowed the acquisition of three-dimensional (3D) images that were "intrinsically" 3D (i.e., without the need for offline reconstruction of adjacent slices) and in "real time" (i.e., displaying motion as it happens). Miniaturization of electronic circuits has made it possible to compact thousands of piezoelectric crystals into the tip of a transesophageal echocardiographic transducer, coupling the quality of transesophageal imaging with a 3D display. As a result, most structures of the heart are represented with anatomic details of unprecedented quality, faithfully mirroring the anatomical reality.[5-8] As 3D echocardiography became widely available (at present, most echocardiographic machines include 3D technology), it was anticipated that 3D TTE and TEE would rapidly replace 2D TTE and TEE. On the contrary, after a decade, 3D echocardiography is not yet fully applied in routine clinical practice, and echocardiographers are disinclined to use 3D echocardiography extensively. Most

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Abbreviations

2D = Two-dimensional

3D = Three-dimensional

AF = Atrial fibrillation

LAA = Left atrial appendage

LAI = Left atrial isthmus

LVOT = Left ventricular outflow tract

TEE = Transesophageal echocardiography

TTE = Transthoracic echocardiography

TV = Tricuspid valve

laboratories perform complete 2D transthoracic or transesophageal echocardiographic studies, followed by a focused 3D examination only in those patients in whom it is believed that 3D echocardiography could potentially provide additional data (e.g., 3D TTE to more precisely quantify left ventricular size and function, 3D TEE in patients with mitral prolapse or flail to better characterize the pathoanatomy of the valve and the likelihood of valve repair).[9]

There are at least three reasons that may explain this reluctance to apply extensively this technology.

First, over decades, echocardiographers and clinical cardiologists were accustomed to analyze the shape and movement of these 2D thin cut planes. A wide array of 2D transthoracic and transesophageal echocardiographic cross-sectional planes have been standardized, precisely describing the cardiac structures that are intersected by the ultrasound beam. A huge number of articles and books have illustrated 2D cross-sections of normal and pathologic cardiac valves and chambers. Angiography, surgical inspections, and anatomic specimens have confirmed the diagnostic accuracy of these 2D cross-sections, making 2D echocardiography the most powerful noninvasive diagnostic technique.

Second, the frame rate of 2D echocardiography (i.e., the number of images per second) and its spatial resolution (i.e., the number of lines per sector [line density]) are still superior to the volume rate (i.e., the number of volumes per second) and spatial resolution (i.e., the number of sectors per volume [sector density]) of 3D echocardiography. Despite the high likelihood that in the near future, technical improvements may reduce or even abolish these gaps between the two technologies, in the most used routine echocardiographic machines, temporal resolution remains low, especially when a large volume size or 3D color Doppler is used.

Third, there is a common belief that experienced echocardiographers are able to mentally reconstruct a 3D image of cardiac structure on the basis of the interpretation of multiple 2D cross-sections, thus making 3D echocardiography an optional if not an unnecessary tool. Although we may agree that experienced echocardiographers may instinctively reconstruct mentally a 3D image derived from multiple 2D sections, this may not be entirely true for less experienced echocardiographers. In particular, we noticed that they are almost totally unaware of which structures lie "nearby" (i.e., behind and in front) a given 2D tomographic plane, that is, what is adjacent in the elevation plane. Because 2D echocardiography will remain for many years the primary imaging modality, in this article we report the use of 3D images to disclose which structures are located "nearby" the corresponding 2D cross-sections. Knowledge of what structure lies nearby a given cut plane may help less experienced echocardiographers in properly maneuvering the transducer. For instance, knowing that the tricuspid valve (TV) lies behind the bicaval cross-sectional view may clarify that to obtain a cross-sectional plane that includes a perpendicular plane of the TV, the echocardiographer must rotate the transducer clockwise. We are convinced that this educational use of 3D echocardiography is a unique tool to expand our understanding of 2D echocardiographic anatomy discovering what we do not see in a given 2D cross-section. In this study, we exclusively used transesophageal images because of the clarity of anatomic details, but the same applies to 3D TTE. Finally, among countless potential tomographic planes, we chose those 2D transesophageal echocardiographic cross-sections "nearby" which there are relevant anatomic structures (sometimes behind or in front a given cross-section, there is only an atrial or a ventricular wall seen in the "en face" perspective). In particular, we disclose those cardiac structures lying "nearby" the following "classic" 2D transesophageal echocardiographic cross-sections: midesophageal long-axis view of the left

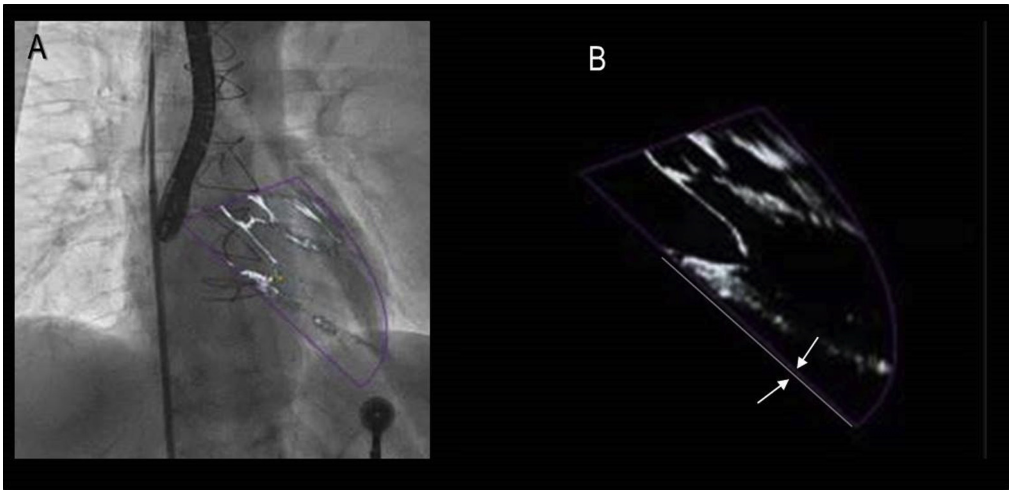

Figure 1 **(A)** Fluoroscopic-echocardiographic fusion imaging in which the transesophageal echocardiographic long-axis view is visualized within the fluoroscopic silhouette of the heart in anteroposterior projection. **(B)** The same magnified imaged without fluoroscopy. The thinness of 2D cross-sections (*arrows*) can be appreciated.