Echocardiographic-Fluoroscopic Fusion Imaging in Transseptal Puncture: A New Technology for an Old Procedure

Francesco F. Faletra, MD, Luigi Biasco, MD, Giovanni Pedrazzini, MD, Marco Moccetti, MD, Elena Pasotti, MD, Laura Anna Leo, MD, Giorgio Cautilli, MD, Tiziano Moccetti, MD, and Mark J. Monaghan, PhD, *Lugano, Switzerland; and London, United Kingdom*

In an era of catheter-based structural heart disease and left-side electrophysiologic interventions, transseptal puncture (TSP) is probably the most common transcatheter procedure. Experienced interventional cardiologists and electrophysiologists may safely perform TSP using fluoroscopic guidance alone. However, at present TSP is usually the first step in complex percutaneous catheter-based structural heart disease procedures and necessitate a precise site-specific TSP. Thus, in these procedures most interventional cardiologists perform TSP under fluoroscopic and two- or three-dimensional transesophageal echocardiographic guidance. The EchoNavigator system may provide a solution by fusing fluoroscopic and transesophageal echocardiographic images. In this review, the authors describe advantages and limitations of this new imaging system in guiding TSP and suggest specific echocardiographic-fluoroscopic fusion imaging perspectives that may facilitate TSP, making it potentially easier and safer. (J Am Soc Echocardiogr 2017;■:■-■.)

Keywords: Catheter-based structural heart disease interventions, Transseptal puncture, Fluoroscopy, Transesophageal echocardiography, Echocardiographic-fluoroscopic fusion imaging

The first attempt to percutaneously cross the interatrial septum (IAS) was successfully performed in 1958 by Constantin Cope,[1] a pioneering cardiologist, who used a curved 7-Fr catheter over a needle with the aim of assessing left atrial (LA) and left ventricular (LV) hemodynamics. Subsequently, Brockenbrough, Braunwald, and Ross[2] refined the procedure (by eliminating, e.g., the need for surgical exposure of the femoral vein). At that time, echocardiography was still in its infancy, and transseptal puncture (TSP) was an invaluable tool used for angiographic and hemodynamic assessment, greatly contributing to our understanding of valvular and congenital heart diseases.[3] However, the ability to estimate LA and LV pressure with the less invasive Swan-Ganz catheter, the increased use of retrograde LV catheterization, and the introduction of Doppler echocardiography as a noninvasive means to assess several hemodynamic parameters resulted in a decline in the use of TSP for diagnostic purposes. For several years, the procedure remained confined to those institutions that regularly performed mitral balloon valvuloplasty or LA arrhythmia ablation.

Over the past two decades, percutaneous catheter-based structural heart disease (SHD) interventions have grown from a small number of interventions designed to treat simple SHD to an impressive array of diseases, which have been traditionally managed surgically. In this context, TSP has experienced a new renaissance. Indeed, crossing the IAS with a TSP permits a direct route into the left atrium and facilitates percutaneous catheter-based treatment of several left-sided SHD pathologies.

The technique of TSP is substantially unchanged since its inception, and experienced interventionalists can safely perform TSP using fluoroscopic guidance alone.[4] However, in difficult cases (i.e., patients with extreme rotation of the cardiac axis, aneurysm of the fossa ovalis [FO], lipomatous septal hypertrophy, large atrial cavities or dilated aortic root, repeated TSP), crossing the FO using fluoroscopy alone may be technically demanding, with a potential hazard for life-threatening complications such as atrial or aortic wall puncture and cardiac tamponade.[5] On the other hand, TSP is usually the first step in complex percutaneous catheter-based SHD procedures that normally require transesophageal echocardiographic (TEE) guidance. Moreover, some of them, such as edge-to-edge mitral valve repair with the Mitraclip system (Abbott Vascular, Abbott Park, Illinois), LA appendage (LAA), occlusion and transfemoral direct annuloplasty with a flexible sleeve (Cardioband®, Valtech Cardio, Or Yehuda, Israel), necessitate a precise site-specific TSP. Thus, in these procedures most interventionalists perform TSP under fluoroscopy accompanied by two-dimensional (2D) or three-dimensional (3D) TEE imaging.[6-9]

A novel software solution (EchoNavigator; Philips Healthcare, Best, The Netherlands) allows fusion between fluoroscopic and TEE images and has been recently proposed to optimize guidance in percutaneous SHD interventions. Although the two modalities are based on different physical principles (ultrasound mechanical waves vs electromagnetic waves) and despite the remarkable differences in image generation (backscattered echoes vs attenuation), fluoroscopy and echocardiography complement each other when fused together in a single image. Both are "real-time" modalities, and both have

From the Dipartimento di Cardiologia, Fondazione Cardiocentro Ticino Lugano, Lugano, Switzerland (F.F.F., L.B., G.P., M.M., E.P., L.A.L., G.C., T.M.); and King's College Hospital, London, United Kingdom (M.J.M.).

Dr. Monaghan has received research grants from Philips and has given several talks supported by Philips. Dr. Faletra has given several talks supported by Philips.

Reprint requests: Francesco F. Faletra, MD, Division of Cardiology, Fondazione Cardiocentro Ticino, Via Tesserete 48, CH-6900 Lugano, Switzerland (E-mail: *francesco.faletra@cardiocentro.org*).

0894-7317/$36.00

http://dx.doi.org/10.1016/j.echo.2017.05.001

Abbreviations

2D = Two-dimensional

3D = Three-dimensional

CT = Computed tomographic

FO = Fossa ovalis

IAS = Interatrial septum

ICE = Intracardiac echocardiographic

LA = Left atrial

LAA = Left atrial appendage

LAO = Left anterior oblique

LV = Left ventricular

MRI = Magnetic resonance imaging

RAO = Right anterior oblique

SHD = Structural heart disease

SVC = Superior vena cava

TEE = Transesophageal echocardiographic

TSP = Transseptal puncture

complementary capabilities that partially offset their intrinsic limitations. The larger field of view of fluoroscopy, for example, counterbalances the narrow field of view of TEE data sets. The optimal visualization of cardiac valves and septa provided by TEE imaging compensates for the scarce or null imaging of soft tissue structures by fluoroscopy. The detailed images of catheters and devices provided by fluoroscopy counterweight the occasionally distorted TEE images caused by blooming, reverberations, and shadowing (Table 1).

Several reports have described the development of this novel imaging modality and early clinical experiences,[10-17] but its specific role during TSP has never been demonstrated in detail. This review, based on experience gained from more than 200 TSPs performed at our institution and at King's College Hospital in London guided by this novel imaging system, aims to cover extensively this topic.

We described the basic principles of this new imaging system, the anatomy of the IAS and its position within the fluoroscopic silhouette, technical aspects of TSP, advantages and limitations of this new imaging system in TSP, and, finally, specific fluoroscopic perspectives that, to our experience, may facilitate TSP, making it potentially easier and safer.

BASIC PRINCIPLES OF ECHOCARDIOGRAPHIC-FLUOROSCOPIC FUSION IMAGING

The basis of the real-time integration between fluoroscopy and echocardiography is substantially the automated localization of the 3D TEE probe into the fluoroscopic space (so-called coregistration). The technology at the base of coregistration has been extensively described elsewhere.[10-12] Briefly, automated localization of the TEE probe consists of two steps: first, a nano–computed tomographic (CT) 3D model of the TEE probe (nano-Pet TM/CT; Mediso, Budapest, Hungary), called digitally reconstruct radiography, is recognized within the fluoroscopic image. Second, the algorithm compares similarities between the fluoroscopic digitally reconstruct radiographic image and the actual fluoroscopic image of the probe, until the best alignment has been achieved. Two or more x-ray projections (we use 30° left anterior oblique [LAO] projections and 30° right anterior oblique [RAO] projections) at the time of TEE probe coregistration may minimize the potential registration errors occurring in the 3D space (especially those in the direction of the fluoroscopic beam) and when the area of interest moves from near to far field. A digitized, green-colored, 3D image of the TEE probe overlying the fluoroscopic image confirms that the 3D TEE probe is correctly coregistered into the fluoroscopic space (Figures 1A–C). Whenever fluoroscopy is activated, the system immediately aligns the orientation of the 2D or 3D echocardiographic images with the fluoroscopic projection (Figures 1D–F). When C-arm angulation is changed, the system immediately registers the new position of the gantry and updates the 3D image orientation. Because no additional hardware is needed, implementation of this system into a catheterization or hybrid room is straightforward, provided that both x-ray and echocardiographic equipment are from the same vendor (i.e., Philips Allura Xper FD20/10 fluoroscopic system and Philips CX50 or iE33, or Philips EPIC; Philips Medical Systems, Andover, Massachusetts).

A dedicated large screen displays the fused imaged. Some specific 3D TEE perspectives cannot be fused with fluoroscopy (i.e., the left side of the atrial septum), because of limitations of C-arm rotation. In these cases, the operator can arrange the display screen in two, three, or four sections that simultaneously depict both 2D or 3D TEE perspectives and fused images. Finally, the fusion imaging system is controlled in the procedural room either by an interventional cardiologist or by the echocardiographer using a wireless mouse.

The following built-in tools facilitate the use of this novel fused image data set:

- Superimposing the entire echocardiographic data set on the fluoroscopic image may be of little clinical utility, because some structures may obscure the ability to see target areas clearly. To avoid this problem, extraneous or surrounding tissue may be cropped in the plane of the fluoroscopic image using the mouse. This allows the imager to reveal those soft tissues most relevant to the procedure (Figures 2A and B).
- Opacity of the 3D TEE image may impede visualization of catheter(s) and device(s) positioned on the fused image. The use of a specific tool that makes the echo images more or less "transparent" relative to the fluoroscopy, allows well-defined imaging of catheters and devices that can be seen through the translucent soft tissues (Figures 2C and D).
- Fiducial landmarks can be positioned on the TEE images, which are instantaneously visible on the fluoroscopic screen, providing a precise fluoroscopic localization of specific targets (with and without superimposed TEE images; Figures 2E and F).
- The ability of the system to merge both 2D (either original or extracted from the 3D data set) and 3D images with fluoroscopy allows the freedom to move from one modality to another according to specific requirements (Figures 2H and G).

ANATOMY OF THE "TRUE" IAS

The key to successfully and safely performing TSP is a thorough understanding of the anatomy of the IAS. Anatomists define the IAS as a membrane that separates the atrial cavities. Consequently, puncture, incision, or removal of the IAS must create a communication between the left and right atrial chambers. According to this definition, the IAS is limited to the thin flap that constitutes the floor of the FO, the embryonic septum primum, and the immediate surrounding margin of its muscular rim (the so-called limbus).

The extensive muscular area near the superior and posterior margins of the FO (the embryonic septum secundum) is actually a two-layered muscular structure formed by a folding of the atrial wall, which externally corresponds to the interatrial groove (also called Sondergaard's or Waterston's groove).[13-15] This "crescent-shaped" folding contains extracardiac adipose tissue and extends superiorly, posteriorly, and inferiorly. A puncture through this folding causes a