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Review article

Fusion Imaging for Procedural Guidance

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ABSTRACT

The field of percutaneous structural heart interventions has grown tremendously in recent years. This growth has fueled the development of new imaging protocols and technologies in parallel to help facilitate these minimally-invasive procedures. Fusion imaging is an exciting new technology that combines the strength of 2 imaging modalities and has the potential to improve procedural planning and the safety of many commonly performed transcatheter procedures. In this review we discuss the basic concepts of fusion imaging along with the relative strengths and weaknesses of static vs dynamic fusion imaging modalities. This review will focus primarily on echocardiographic-fluoroscopic fusion imaging and its application in commonly performed transcatheter structural heart procedures.

Técnicas de fusión de imagen en los procedimientos intervencionistas

Palabras clave:
Fusión de imágenes
Enfermedad valvular
Cardiopatía estructural

RESUMEN

El área de las intervenciones percutáneas en la cardiopatía estructural ha crecido de manera exponencial en los últimos años. Ello ha estimulado en paralelo el desarrollo de nuevos protocolos y tecnologías en el campo de la imagen para facilitar los procedimientos percutáneos. La fusión de imagen es una atractiva nueva tecnología que combina las posibilidades de 2 modalidades de imagen, lo cual tiene el potencial de mejorar la planificación del procedimiento y la seguridad de muchos de los procedimientos transcatéter habituales. En esta revisión se discuten conceptos básicos de fusión de imagen y se comentan las fortalezas y debilidades de las modalidades de fusión dinámica y estática. Se centra prioritariamente en la fusión de imagen de la ecocardiografía y la fluoroscopia y en su aplicación a los procedimientos transcatéter.

Abbreviations

2D: 2-dimensional
3D: 3-dimensional
CT: computed tomography
MRI: magnetic resonance imaging
MSCT: multi-slice computed tomography
RA: rotational angiography
TEE: transesophageal echocardiography

INTRODUCTION

In the last decade the field of percutaneous transcatheter structural heart interventions has grown exponentially. Due to advances in both technology and procedural techniques, multiple structural procedures, including transcatheter aortic valve replacement (TAVR), transcatheter mitral valve repair, paravalvular leak closure, left atrial appendage occlusion, and many other techniques are commonly being performed in the cardiac catheterization laboratory worldwide. Along with these minimally-invasive techniques has come a greater need for precise preprocedural and real-time intraprocedural imaging guidance to facilitate safe and successful repair procedures without the availability of direct visualization provided by open heart surgery. A central challenge of fluoroscopic imaging during intracardiac structural procedures is the challenge of correlating patient anatomy with 2-dimensional (2D) fluoroscopic views. Fusion imaging is a novel technological advance that allows for integration of highly detailed echocardiographic, computed tomographic, and magnetic resonance cardiac imaging with fluoroscopy. This review will cover the basic principles of fusion imaging and also detail specific clinical applications of echocardiographic-fluoroscopic fusion imaging for a variety of percutaneous transcatheter structural heart procedures.

FUSION IMAGING: BASIC CONCEPTS

In contrast to open heart surgery, percutaneous structural interventions do not permit direct visualization of the cardiac

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anatomy and pathology and, as a result procedural success, is dependent on imaging guidance. Optimal imaging in structural heart disease provides a 3-dimensional (3D) image that matches the underlying anatomic pathology, allowing procedural planning, intraprocedural guidance, and postprocedure assessment. Traditionally, fixed-projection 2D-fluoroscopy has been the primary imaging tool for interventional cardiologists. Fluoroscopy provides visualization of the position and course of interventional catheters and wires in a wide field of view. Biplane fluoroscopy helps by providing a second 2D projection usually in an orthogonal plane to the first projection to guide 3D navigation within the cardiovascular system. The addition of contrast lumenography allows delineation of coronary artery anatomy and cardiac chambers. However, fixed projection 2D-fluoroscopy is limited in the characterization of soft tissue and complex cardiac anatomy. The limitations of 2D-fluoroscopy for structural intervention can be mitigated by combining or "fusing" fluoroscopy with other imaging modalities that provide better characterization of anatomy and spatial resolution. Fusion imaging is the overlay of images acquired from different imaging modalities within the same spatial coordinate space. This process of image correlation is termed "coregistration" or "image registration". Several methods of image registration have been developed that provide fusion imaging for a variety of image-guided procedures such as radiation therapy, minimally-invasive surgery, and interventional radiology.[1] Fusion or hybrid imaging using 2D-fluoroscopy in combination with static or dynamic images provided by multi-slice computed tomography (MSCT), magnetic resonance imaging (MRI), and transesophageal echocardiography (TEE) have been successfully employed for cardiac structural interventions.

Static Fusion Imaging: "Roadmapping"

Static fusion imaging typically refers to the use 3D data sets acquired prior to the planned procedure that are then fused with intraprocedural fluoroscopy to provide a "roadmap" for the intervention. The most common fusion modality for this purpose is 3D MSCT-fluoroscopy. A detailed description of the method for image registration for 3D MSCT-fluoroscopy fusion is beyond the scope of this review, but this process uses software algorithms in combination with manual refinement using anatomic regions of interest to register the 3D MCST image with fluoroscopy.[1] Systems for 3D MSCT-fluoroscopy fusion imaging are currently clinically available (Syngo DynaCT, Siemens Healthcare, Erlangen, Germany; HeartNavigator, Philips Healthcare, Andover, MA). Once the computed tomography (CT) datasets are registered, the resulting 3D CT "roadmap" can be overlaid on a real-time 2D-fluoroscopy screen to provide procedural guidance.[2,3] Three-dimensional MSCT-fluoroscopy has been used successfully in multiple structural interventions including paravalvular leak closure,[4,5] TAVR,[3,6] left atrial appendage occlusion,[7] and pulmonary vein stenting.[8]

In addition to 3D MSCT-fluoroscopy fusion, rotational angiography (RA) has been used for congenital heart disease and vascular interventions.[9–11] Rotational angiography uses C-arm rotation in concert with timed contrast injection to generate multiple 2D datasets that can be reconstructed into a 3D volumetric dataset.[9] The 3D RA "roadmap" overlay can follow the C-arm during the intervention or the C-arm can follow manipulation of the 3D RA image. The use of 3D RA for procedural guidance has been described in pulmonary valve interventions[12] and pulmonary artery balloon angioplasty.[13] In TAVR procedures, RA 3D reconstructions have been used for determining optimal 2D-fluoroscopy deployment angle,[14] annular measurements,[15] coronary ostium heights,[16] and for the evaluation of postimplantation valve expansion.[17] Three-dimensional RA-fluoroscopy fusion has been demonstrated to reduce fluoroscopy time during stenting of coarctation in pediatric populations.[11]

Magnetic resonance imaging-fluoroscopy fusion imaging is another example of procedural "roadmapping." Preprocedural MRI imaging is registered to fluoroscopy using software algorithms in combination with fiducial markers and manual manipulation.[18,19] Potential benefits of MRI-fluoroscopy fusion include a reduction in ionizing radiation dose and the ability to incorporate cardiac and respiratory motion in the preprocedural MRI imaging, which may improve the efficacy of procedural imaging alignment.[20,21]

Although static fusion imaging has tremendous potential for improved planning and execution of interventional structure heart procedures, there are limitations with respect to positional accuracy and procedural monitoring. As with any fusion imaging, there is the possibility for misalignment with 2D fluoroscopy due to registration error. A study of an MRI-fluoroscopy fusion 2D-3D method that used internal markers for image registration reported a median measured error of 2.15 mm.[19] Registration misalignment can be somewhat mitigated by manual manipulation of the superimposed images using unique anatomic landmarks. However, since the fused 3D volume is a static "roadmap", changes in patient positioning or motion during the procedure can introduce new error or amplify underlying image registration misalignment. Increased C-arm spin rates, ECG-gating and software-based algorithms may provide reasonable correction for periodic respiratory or cardiac motion. However, the nonperiodic anatomic motion that is introduced by manipulation with rigid catheters or devices and which occurs during the interventions presents a challenging source of error without clear solutions. Finally, although use of static fusion imaging provides a "roadmap" for planned interventions, these modalities generally do not provide the ability to comprehensively evaluate intraprocedural complications or determine postprocedure outcomes.

Dynamic Fusion Imaging: TEE-fluoroscopy

The ideal imaging modality for percutaneous structural heart disease interventions would provide excellent real-time characterization of anatomy with precise tracking and localization of devices and catheters. Echocardiography provides exceptional visualization of soft tissue as well as real-time hemodynamic information. However, echocardiography has a limited field of view and ultrasound is subject to interference related to interventional devices and catheters. X-ray fluoroscopy provides a large field of view with excellent visualization of interventional devices but lacks fidelity in soft tissue characterization. Fusion of echocardiographic and fluoroscopy imaging harnesses the attributes of both modalities for optimization of structural heart disease interventions in the cardiac catheterization laboratory. The fusion and overlay of TEE images on the fluoroscopic projection provides enhanced appreciation of the orientation of interventional devices or catheters to the cardiac anatomy and allows for more precise navigation and device deployment.

Initial solutions for echocardiography-fluoroscopy image registration relied on electromagnetic tracking devices[22,23] that required additional hardware and modifications to existing imaging platforms. Recently, commercially available software has been developed (EchoNavigator-Philips Healthcare, Best, The Netherlands; TrueFusion-Siemens Healthineers, Erlangen, Germany) that allows for automated registration of 2D and 3D transesophageal echocardiographic images with X-ray fluoroscopy using existing imaging platforms without the need for additional hardware.

The process of image registration requires localization and tracking of the transesophageal probe position within the X-ray

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