Impact of fused computed tomography and fluoroscopy in the catheterization laboratory

Impact de la fusion scanner et fluoroscopie en salle de cathétérisme

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Received 3 February 2018; received in revised form 11 March 2018; accepted 12 March 2018

Summary The development of structural interventional catheterization for acquired or congenital heart disease was made possible through concomitant advances in catheterization techniques/tools and imaging techniques (fluoroscopy, ultrasound, magnetic resonance imaging and computed tomography). Imaging should provide an accurate view of the lesions and the surrounding cardiac structures, as well as the medical devices and catheters used. Here, we address the subject of image fusion. The principle of image fusion is based on the superposition of several imaging techniques: real-time fluoroscopy and multislice imaging performed offline or ultrasound imaging performed simultaneously. The goals are to improve the overall visualization of the organ and the surrounding structures, and to help the interventional cardiologist to interpret fluoroscopy images.

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KEYWORDS
Heart disease; Catheterization; Fluoroscopy; Tomography; Multimodal imaging

Abbreviations: 2D, two-dimensional; 3D, three-dimensional; CABG, coronary artery bypass graft; CT, computed tomography; CTO, chronic total occlusion; LAA, left atrial appendage; TOE, transoesophageal echocardiography.

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https://doi.org/10.1016/j.acvd.2018.03.001
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Please cite this article in press as: Fresse-Warin K, et al. Impact of fused computed tomography and fluoroscopy in the catheterization laboratory. Arch Cardiovasc Dis (2018), https://doi.org/10.1016/j.acvd.2018.03.001
Background

Computed tomography (CT)/X-ray image fusion is a new technology that allows the overlay of a three-dimensional (3D) CT model onto fluoroscopic images obtained in real time. CT scan systems provide a 3D reconstruction of a structure of interest, which can improve the two-dimensional (2D) spatial visualization of images obtained during a real-time medical intervention. This imaging technique has been described previously in interventional neuroradiology [1–4], in abdominal and vascular interventional radiology [5–8] and in cardiology, during atrial fibrillation ablation procedures [9–12]. In the context of congenital heart disease, image fusion has been reported to be helpful in complex haemodynamic procedures [13–15].

The advantages of CT image fusion are manifold. First, as a result of the full 3D registration between the CT volume and the X-ray system, the rotation of the CT volume is linked to the rotation of the X-ray system, enabling assessment of the best position for the X-ray system with respect to the anomaly, with no need for additional X-ray exposure. Second, during the procedure, image fusion facilitates optimal positioning of catheters, guides and balloons or devices, with minimum injection of radiocontrast agent. Third, because it is possible to visualize specific thoracic structures, the angiography before the interventional catheterization is simplified: for example, aortography of the coronary tree before pulmonary revalvulation is not mandatory because the coronary arteries can be localized on image fusion. Hence, using CT scans that are usually available from preoperative exploration, image fusion provides additional guidance during interventional catheterization, while limiting exposure to radiation and radiocontrast agents.

In this review we describe various procedures in acquired or congenital heart disease that could be facilitated by the use of image fusion.

Real-time 3D reconstruction and image fusion

Before CT scan/X-ray image fusion in the catheterization laboratory, an electrocardiogram-gated CT scan must be performed with contrast injection, allowing good opacification of the target structure. Before the examination, the first step is the segmentation of the CT scan, to delineate the structures of interest for fusion, using a dedicated workstation (Video A.1). Planning lines may also be added at this stage, and integrated into the segmented 3D model. During the intervention, the fusion software prepares a conic projection of the 3D model according to the C-arm geometrical configuration, which is then superimposed over the real-time fluoroscopy 2D images. The initial default registration is further refined manually, by sliding the superimposed model into alignment with remarkable landmarks, either from tableside or from the control room. This step may be performed from two different angulations at the operator’s convenience.

The accuracy of the image overlay is then confirmed visually, through the use of contrast angiography. Finally, the CT overlay is available for live guidance, with no need for further operator interaction; C-arm angulations and table movements are synchronized with the 3D model. The model adapts continuously to system geometrical changes. This enables the optimal working view to be reached without X-ray exposure. This entire workflow takes 15 min per examination, including 10 min for the segmentation step at any time before the procedure and 5 min for registration during the examination. Because of the simplicity of the segmentation step, and the fact that it can be done on the workstation outside of an examination, training can be done within a few procedures. Because most complex congenital or acquired heart diseases usually require a CT scan for exploration, this technique does not lead to additional patient radiation exposure.

Image fusion and coronary artery disease

Locating a coronary artery bypass graft (CABG) that requires follow-up evaluation may be difficult with coronary angiography, especially for venous and radial artery grafts, which may involve variable proximal anastomosis locations. As a consequence, the procedure may be long, which can result in elevated radiation exposure [16] and increased nephotoxic complications [17], particularly in high-risk patients (e.g. elderly or overweight patients and those with

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multiple vascular diseases or renal failure). We have evaluated the impact of image fusion on coronary angiography for the detection of a CABG [18]. We found that 3D image fusion of coronary angiography with fluoroscopy improved CABG detection and reduced the time necessary for CABG localization, as well as total procedure duration and exposure to radiation and contrast media (Video A.2).

Image fusion of CT angiography on real-time fluoroscopic images has also been used during percutaneous coronary intervention in patients with coronary chronic total occlusion (CTO), to visualize the occluded vessel. Ghosh-haja et al. [19] showed that image fusion could increase patient safety and operator confidence during antegrade dissection, by confirming that the dissection is performed down the main artery rather than deviating into a side branch, with the risk of inducing a perforation. Randomized studies are needed to confirm the impact on procedural features, including procedural time, contrast volume and radiation exposure.

Image fusion and left appendage closure

A successful left atrial appendage (LAA) occlusion procedure requires multiple imaging modalities, including transesophageal echocardiography (TOE) or 3D multidetector CT and fluoroscopy. This procedure is particularly challenging, as the LAA and surrounding structures vary widely in morphology and 3D relationship. Overlaying CT data onto real-time fluoroscopic images during LAA occlusion procedures has been found to be feasible and safe. Roy et al. [20] recently reported that the fusion of 3D multidetector CT and fluoroscopy images reduced the contrast volume as well as the procedural and fluoroscopy times, thus contributing to the optimization of the LAA procedural success (Fig. 1), with a reduction in associated complications. Nevertheless, although CT image fusion seems to be helpful in guiding the procedure, TOE remains the gold-standard imaging modality for assessment of device positioning and LAA exclusion.

Image fusion and valvular heart disease

Another application for image fusion is to assist in the repair of heart valves. Unlike transthoracic echocardiography and TOE, the CT scan is not considered as a gold-standard imaging modality for assessment of the heart valve. However, it provides high spatial resolution images, and CT image fusion appears to be a unique tool for planning and guiding complex valve interventions.

Mitra valve stenosis and recurrent mitral valve regurgitation are currently treated by implantation of a transcatheter aortic valve prosthesis in the mitral position. However, the guiding and positioning of the device can be challenging, as fluoroscopy alone cannot identify the complex cardiac structures, and 3D echocardiography delivers insufficient imaging of wires and catheters. In this context, CT image fusion is a source of accurate anatomical information, allowing identification of the valve landing zone and the optimal C-arm positioning (perpendicular to the mitral annular plane) for correct valve deployment, with visualization of potential narrowing of the left ventricular outflow track [21]. Percutaneous transapical access has been successfully guided by fused 3D CT and fluoroscopy imaging [22,23]; the left ventricle can be punctured accurately at a safe distance from the coronary arteries, thus potentially reducing transapical access-related complications.

MitraClip® (Abbott, Abbott Park, IL, USA) procedures are mostly performed under TOE planning and guidance, but CT image fusion can help to secure the atrial septal puncture, guide the MitraClip® into the left atrium and ventricle, and accurately position the device in the centre of the mitral annulus. The target for the puncture can be defined by the placement of a landmark on the interatrial septum, at a predefined distance from the mitral valve, and away from important structures, such as the ribs, coronary arteries and lungs, to reduce complications. The advantage of CT image fusion in MitraClip® procedures has yet to be demonstrated in a clinical study (Fig. 2). Nevertheless, CT image fusion cannot replace the accurate real-time TOE view for clip positioning and delivery.

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Preprocedural planning of direct and indirect mitral valve annuloplasty usually involves CT scanning to assess the 3D anatomy of the mitral valve apparatus, including existing prosthetic devices and surrounding structures, whereas fluoroscopy is routinely used for guidance during the procedure. However, fluoroscopy cannot characterize non-radiopaque structures, and only provides 2D projections, suggesting that CT image fusion could be helpful to improve spatial information and localize the mitral valve annulus accurately, so that the C-arm position can be adjusted for precise direct or indirect annuloplasty ring implantation.

During transcatheter aortic valve implantation, CT image fusion is a useful modality for additional guidance. Valve positioning is facilitated by the identification in the fusion image of the appropriate angle for a co-planar view of the sinus segments. The overlay of the CT and fluoroscopic images reveals real-time anatomical features that would not be available with fluoroscopy alone [24], including the position of the annulus and the position of the coronary artery ostia in relation to the annulus. Real-time assessment of these anatomical structures supports effective valve positioning and deployment, while minimizing the use of contrast agent (Fig. 3) [25,26]. The main limitation of CT imaging is the non-dynamic and remote acquisition mode, whereas the visualization of valvular calcifications in fluoroscopy enables the interventional cardiologist to be constantly aware of the position of the aortic annulus in "real time". Nevertheless, a definite advantage of image fusion is the detection of the exact localization of the coronary artery ostia, for oriented implantation of the valve following guided anatomical rotation [27].

One of the difficulties associated with the closure of a paravalvular leak is knowing how to locate the leak with respect to the valve on the fluoroscopy image, and therefore where to look for the leak orifice. Before the procedure, a CT scan can provide information about the size and shape of the leak, the degree of surrounding calcification, the interaction with other cardiac structures and the overall best access strategies for transcatheter repair. During the procedure, while echocardiography is a major help in locating and guiding the catheterization of the paravalvular leak, CT image fusion enables the interventional cardiologist to define the position of the C-arm, which places the leak tangentially relative to the valve ring. It is then possible to identify the
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regurgitant orifice, and to check directly on the fused fluoroscopic image that the guide goes through the leak rather than through the valve. Krishnaswamy et al. [24] found that the fusion of CT and fluoroscopic information was particularly helpful in patients presenting for paravalvular leak closure. In these patients, the optimal site of transseptal puncture is marked on the CT scan to guide paravalvular leak crossing, and the duration of TOE is minimized. Reductions in radiation exposure, contrast volume and procedural time are anticipated, but should be confirmed in future studies.

Image fusion and congenital heart disease

CT image fusion is used increasingly to facilitate congenital heart disease diagnosis, and to guide interventional procedures in a variety of conditions, including aortic coarctations (Fig. 4; Video A.3), pulmonary trunk angioplasty and revalvulation (Fig. 5; Video A.4), patent ductus arteriosus closure (Fig. 6) and atrial septal defect closure [28–32]. Compared with standard fluoroscopy, CT has a greater diagnostic utility in identifying complex vascular structures and atypical anatomies that have been modified further by multiple previous surgeries [33]. Beyond facilitating diagnosis and procedural guidance, the potential benefits of integrating 3D CT images with fluoroscopic procedures include increased interventional efficacy and reduced overall radiation exposure and contrast dose [13]. Prospective studies are needed to assess the clinical implications.

Conclusions

CT image fusion appears to be a new imaging modality that can be a useful adjunct to standard real-time fluoroscopy and echocardiography for the management of specific acquired and congenital heart diseases in the catheterization laboratory; it is particularly useful for interventional structural catheterization involving atypical anatomies or localizations that cannot be readily visualized by echocardiography. Because CT image fusion is performed during the diagnostic workup, there is no additional exposure of the patient to ionizing radiation during the procedure. Preliminary studies suggest a facilitated procedure requiring less radiation exposure and smaller volumes of contrast agent. The main limitation is the preregistration of the CT scans, which does not provide a real-time image of the heart and vessels. Furthermore, cardiac and respiratory movements, as well as interventional catheters, induce changes in the anatomy that have to be taken into consideration. A quantitative analysis of the contribution of CT image fusion is needed, especially for usual and comparable interventions, to evaluate the real impact of this new imaging modality on our current practice.

Figure 4. Aortic coarctation. (A) The CT scan shows aortic coarctation (white arrow). (B) Overlay of the CT scan and fluoroscopy, with the tracheal bifurcation as the landmark used for registration (yellow arrow); optimal angle for imaging of the aortic arch to position the stent (white arrow). (C) Angioplasty with implantation of a covered stent (CP Stent™; Numed Healthcare, Sheffield, UK), with a good final result (white arrow) (Valve ASSIST Z; GE Healthcare).

Figure 5. Pulmonary angioplasty and revalvulation; patient with operated complex congenital heart disease presenting symptomatic pulmonary stenosis (20 mm diameter homograft). Angioplasty and revalvulation were done using CT/fluoroscopy fusion, with the mechanicaortic valve used as the registration landmark (A, white arrow). The first stent was implanted in the pulmonary trunk (A, yellow arrow), then the second and third (B, white arrow), before implantation of the SAPIEN XT valve (Edwards Lifesciences, Irvine, CA, USA) (C, yellow arrow) (Valve ASSIST Z; GE Healthcare).
Sources of funding

None.

Acknowledgments

The authors wish to thank Dr. Laurianne Le Gloan, MD, Dr. Nadir Benbrik, MD, Dr. Benedicte Romefort and Mme Nathalie Musseau for their contributions.

Disclosure of interest

The authors declare that they have no competing interest.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.acvd.2018.03.001.

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Please cite this article in press as: Fresse-Warin K, et al. Impact of fused computed tomography and fluoroscopy in the catheterization laboratory. Arch Cardiovasc Dis (2018), https://doi.org/10.1016/j.acvd.2018.03.001
Compressed red blood cells (RBCs) and white blood cells (WBCs) are often used in transfusions to improve blood flow and oxygen delivery. These cells can be concentrated or washed to remove plasma and other components.

RBCs are particularly valuable in situations where a patient needs a higher concentration of red blood cells to increase oxygen-carrying capacity. For example, in cases of severe anemia or when the patient has a low hemoglobin level. In these cases, using concentrated RBCs can help improve blood oxygen saturation and overall health outcomes.

WBCs, on the other hand, are used for their immune-boosting properties. Patients undergoing chemotherapy or who have compromised immune systems may benefit from WBC transfusions to help fight infections and infections. It's crucial to maintain a balance between the two types of cells to ensure optimal outcomes.

In conclusion, while both RBCs and WBCs offer unique advantages, the choice of which to use depends on the specific needs of the patient and the clinical context. Healthcare professionals must carefully consider these factors before making decisions about transfusion therapy to ensure the best possible outcomes.