Archives of Cardiovascular Disease (2016) 109, 128—142

Available online at ScienceDirect www.sciencedirect.com

Elsevier Masson France EM|consulte www.em-consulte.com/en

REVIEW

Cardiac imaging of congenital heart diseases during interventional procedures continues to evolve: Pros and cons of the main techniques

Évolution de l'imagerie des cardiopathies congénitales en salle de cathétérisme : avantages et inconvénients des différentes techniques

Sebastien Hascoët[a,b,*,1], Karine Warin-Fresse[c], Alban-Elouen Baruteau[a,d], Khaled Hadeed[b], Clement Karsenty[b], Jérôme Petit[a,1], Patrice Guérin[c,1], Alain Fraisse[e,1], Philippe Acar[b,1]

[a] *M3C Marie-Lannelongue Hospital, Department of Paediatric and Congenital Cardiac Surgery, Paris-Sud University, Paris, France*
[b] *M3C CHU Toulouse, Paediatric and Congenital Cardiology, Children's Hospital, Paul-Sabatier University, Toulouse, France*
[c] *M3C CHU Nantes, Nord Laennec Hospital, Nantes, France*
[d] *Morgan Stanley Children's Hospital at New York Presbyterian, Columbia University Medical Center, Department of Paediatric Cardiac Surgery, New York, NY, USA*
[e] *Royal Brompton Hospital, Imperial College London, Department of Paediatric Cardiology, London, United Kingdom*

Received 25 September 2015; received in revised form 9 November 2015; accepted 13 November 2015
Available online 5 February 2016

Abbreviations: 2D, two-dimensional; 3D, three-dimensional; ASD, atrial septal defect; CHD, congenital heart disease; CT, computed tomography; MRI, magnetic resonance imaging; TOE, transoesophageal echocardiography; TTE, transthoracic echocardiography; VSD, ventricular septal defect.

* Corresponding author. Pôle des cardiopathies congénitales, hôpital Marie-Lannelongue, 133, avenue de la Résistance, 92350 Le Plessis-Robinson, France.
E-mail address: s.hascoet@ccml.fr (S. Hascoët).

[1] Working Group on Pediatric and Congenital Interventional Cardiology, French Pediatric and Congenital Cardiology Branch of the French Society of Cardiology.

http://dx.doi.org/10.1016/j.acvd.2015.11.011

KEYWORDS
Congenital heart diseases;
Fusion imaging;
3D echocardiography;
Echonavigator®;
3D printing

Summary Cardiac catheterization has contributed to the progress made in the management of patients with congenital heart disease (CHD). First, it allowed clarification of the diagnostic assessment of CHD, by offering a better understanding of normal cardiac physiology and the pathophysiology and anatomy of complex malformations. Then, it became an alternative to surgery and a major component of the therapeutic approach for some CHD lesions. Nowadays, techniques have evolved and cardiac catheterization is widely used to percutaneously close intracardiac shunts, to relieve obstructive valvar or vessel lesions, and for transcatheter valve replacement. Accurate imaging is mandatory to guide these procedures. Cardiac imaging during catheterization of CHD must provide accurate images of lesions, surrounding cardiac structures, medical devices and tools used to deliver them. Cardiac imaging has to be 'real-time' with an excellent temporal resolution to ensure 'eyes—hands' synchronization and 'device—target area' accurate positioning. In this comprehensive review, we provide an overview of conventional cardiac imaging tools used in the catheterization laboratory in daily practice, as well as the effect of recent evolution and future imaging modalities.

MOTS CLÉS
Cardiopathies congénitales ;
Imagerie de fusion ;
Échocardiographie 3D ;
Echonavigator® ;
Impression 3D

Résumé Le cathétérisme cardiaque a contribué aux progrès réalisés dans la prise en charge des cardiopathies congénitales. Il a tout d'abord permis de mieux appréhender l'anatomie et la physiologie des malformations complexes. Le cathétérisme est de nos jours de plus en plus interventionnel, suppléant ou complétant la chirurgie cardiaque. Il permet entre autres l'occlusion de shunt, la dilatation de valves, vaisseaux ou conduits sténosés et le remplacement valvulaire percutané. Une imagerie de précision est nécessaire en salle de cathétérisme pour guider ces interventions. Cette imagerie doit permettre de bien visualiser les lésions à traiter, les structures avoisinantes, les dispositifs médicaux et les systèmes permettant de les acheminer. Cette imagerie doit être temps-réel pour permettre à l'opérateur une bonne coordination « main—œil » et « prothèse—zone cible ». Dans cette revue générale, nous abordons les avantages et les inconvénients des outils d'imagerie actuellement utilisés en salle de cathétérisme, l'impact des évolutions récentes ainsi que les perspectives futures.

Introduction

Cardiac catheterization has contributed to the progress made in the management of patients with congenital heart disease (CHD). It is widely used to percutaneously close intracardiac shunts [1,2], to relieve obstructive valvar or vessel lesions, and for transcatheter valve replacement [3—5]. Cardiac imaging has always been closely related to the development of cardiac catheterization. Catheterization became feasible under fluoroscopy [6]. It remains the cornerstone of cardiac imaging, but two-dimensional (2D) and three-dimensional (3D) echocardiography has become a complementary useful tool in the catheterization laboratory [7]. Fusion imaging between fluoroscopy and echocardiography or tomography further assist complex percutaneous procedures [8,9]. Multi-modalities imaging in the catheterization laboratory is thus nowadays available. In this comprehensive review, we provide an overview of conventional cardiac imaging tools used in catheterization laboratories in daily practice, as well as the effect of the recent evolution of and future imaging modalities. First, conventional fluoroscopy and its improvement are described. Then, the effect of multimodal echocardiography is discussed with regards to CHD current practice in the catheterization laboratory. Other 3D imaging techniques are further described, with their potential application in CHD. The focus is on the strengths and weaknesses of each imaging modality.

How the feasibility of cardiac catheterization was demonstrated

The first cardiac catheterization in man was demonstrated by X-ray imaging in 1929 [6]. At age 25, while receiving clinical instruction in surgery, Werner Forssmann (1904—1979) passed a urethral catheter through one of his left antecubital veins until its tip entered the right atrium. He then walked to the radiology department where an X-ray was taken [6]. Together with Cournand and Richards, he obtained the Nobel Prize in 1956. During his Nobel lecture, Cournand stated elegantly that cardiac catheterization was the 'key in the lock' to summarize its effect on the diagnosis and treatment of heart diseases. In the 1950s, dynamic images of heart cavities were feasible through the development of cineangiograms on roll films and image intensifiers.