Interventional catheterization and echocardiography: An indefectible link illustrated by atrial septal defect closure

Cathétérisme interventionnel et échocardiographie: un lien indéfectible illustré par la fermeture percutanée de communication interatriale

Clément Karsenty a, b, *, Khaled Hadeed a, Philippe Acar a

a Service de Cardiologie Pédiatrique, Hôpital des Enfants, CHU Toulouse, 31000 Toulouse, France
b Institut des Maladies Métaboliques et Cardiovasculaires, Institut National de la Santé et de la Recherche Médicale, U1048, Université de Toulouse, 31432 Toulouse, France

Received 31 January 2018; received in revised form 14 March 2018; accepted 19 March 2018
Available online 13 April 2018

MOTS CLÉS
Cathétérisme interventionnel ; Échocardiographie ; Communication interatriale

Before the 1970s, diagnosis of congenital and acquired heart disease was achieved by a combination of physical examination, electrocardiography and invasive cardiac catheterization. During the 1970s, simple motion-mode imaging was available to define simple cardiac structures [1], then technology improved to provide two-dimensional (2D) real-time imaging of the heart and Doppler, which subsequently revolutionized non-invasive assessment. By the late 1980s, echocardiography had developed to the point where it began to replace cardiac catheterization as the primary diagnostic tool for congenital heart disease, reducing the number of cardiac catheterizations.

Interventional cardiac catheterization was launched by Dr Gruntzig, with the first coronary angioplasty, and its development continued with Dr Porstmann’s use of an IVALON® (First Aid Bandage Co., New London, CT, USA) plug to close persistent patent ductus arteriosus, and Dr King’s devices for the closure of secundum atrial septal defects (ASDs) [2] to rescue cardiac catheterization. Nevertheless, technical difficulties (i.e. limited retrievability and large delivery systems) and residual shunts plagued the development of these devices, and their application remained limited.

Abbreviations: 2D, two-dimensional; 3D, three-dimensional; ASD, atrial septal defect; cath-lab, catheterization laboratory; TOE, transoesophageal echocardiography.
* Corresponding author at: Service de Cardiologie Pédiatrique, Hôpital des Enfants, 330, avenue de Grande-Bretagne, 31059 Toulouse Cedex 9, France.
E-mail address: clement.karsenty@hotmail.fr (C. Karsenty).

https://doi.org/10.1016/j.acvd.2018.03.003
1875-2136/© 2018 Published by Elsevier Masson SAS.
As a result of the parallel technological evolution of cardiac ultrasound — including the development of “real-time” three-dimensional (3D) echocardiography at the end of the 20th century, which provided descriptions of defects to match those of an anatomist — interventional catheterization moved forward.

ASD is a perfect example of this link between cardiac imaging and cardiac catheterization. King et al. reported the first attempted transcatheter closure of a secundum ASD in 1975, with a DACRON® (Invista, Wichita, KS, USA) polyester fabric-covered steel umbrella [2]. This was followed by the development of the Rashkind single umbrella device (USCI Angiographic Systems, Tewksbury, MA, USA) [3], which consisted of multiple wire “legs” with fishhook-like ends for anchoring on the atrial septum, at the rim of the defect. The fishhooks made placement of the device a harrowing experience, and dislodgement of the device an unacceptable risk. For this reason, visualization of the size and position of the defect within the atrial septum, and assurance of, for example, a good relationship between the device and the atrioventricular valves or pulmonary venous entry, were advisable during the procedure [4]. In the late 1980s, with the development of the Lock Clamshell Occluder (USCI Angiographic Systems) [5], which consists of two sets of articulated wire arms with DACRON® patches, small-to-moderate defects in a central position could be closed. However, only secundum defects of <20 mm diameter were closable. The next innovation was the self-centring device, allowing closure of defects approaching 40 mm in diameter, and those with rim deficiencies in the retroaortic area (the “buttoned” double-disc device and the ASD occluder system). All the devices led to great success, but also surgical removal, arm fracture, residual shunt and thrombus formation. Thus, in the late 1990s, the CardioSEAL® device (NMT Medical, Boston, MA, USA), the AMPLATZER™ Septal Occluder (St. Jude Medical, St. Paul, MN, USA) and the HELEX™ Septal Occluder (W. L. Gore & Associates, Flagstaff, AZ, USA) [6] emerged.

These devices not only provided an alternative to surgical closure, but also produced a number of new challenges, overcome mainly by echocardiography. Firstly, echocardiography can define the best geometric profile between different devices [7]. Sizing the device is a crucial part of the procedure: when the device is undersized, embolization or residual shunting can occur; by comparison, an oversized device increases the risk of conflict with surrounding cardiac structures — particularly the risk of aortic root erosion [8]. Thus, 3D transthoracic echocardiography provides unique en face views of ASDs, and allows better sizing than 2D echocardiography [9], including dynamic shape change during the cardiac cycle (smaller in diastole and larger in systole) [10].

The assessment and sizing of every rim around the defect is feasible in one view. Interestingly, ASDs are not typically circular “holes,” but are complex structures, often irregularly shaped or fenestrated, which are difficult to visualize in two dimensions. Therefore ASD anatomy assessed in 3D influences patient and device selection [11].

As a result of the miniaturization of the 3D transducer [12], 3D transoesophageal echocardiography (TOE) now plays a pivotal role in real-time 3D guidance of percutaneous procedures [13]. The ASD shape, maximal diameter and area assessed by 3D-TOE may be sufficient to determine the device size without balloon sizing in children. TOE is then used to monitor the deployment of the septal occluder, documenting the placement of the left disk within the left atrium, the stent within the atrial septum and the right-sided disk on the right side of the atrial septum. TOE is used to document complete occlusion of the defect, both before and after release of the device from the delivery cable. Hence, 3D imaging can reduce procedural time, fluoroscopy time and the occurrence of unexpected deleterious outcomes. Intracardiac echocardiography is another safe and effective modality for closing complex ASDs [14]. 3D echocardiography has enhanced our understanding of secundum ASD anatomy and the spatial relationship with nearfield structures, and has improved patient and device selection, but has also provided imaging conceptualization to help with the development of closure devices. Over the course of 40 years, closure devices have been made with smaller material, knitted and self-expandable wire frames with minimally protruding elements, endothelialization-enhancing fabric and self-expanding, self-centring and recapturing capacities. The story of ASD closure highlights how progress in imaging methods has changed interventional catheterization, and how echocardiography has grown increasingly in the catheterization laboratory (cath-lab), becoming an indispensable part of transcatheter interventions [15].

The link between imaging and the interventional cath-lab is also essential for expanding transcatheter interventions in valvular and structural heart disease. Closure of paravalvular leaks has become an extremely important and successful procedure. 2D imaging, either by echocardiography or by angiography, can be confusing in the analysis of the relationship between the paravalvular leak and the corresponding prosthetic valve. 3D modalities are absolutely necessary during the procedure, and new software solutions to fuse and synchronize angiographic and echocardiographic image information are promising. Indeed, no paravalvular leak closure can be accomplished without 3D monitoring, highlighting the interdependency between the echocardiographer and the interventionist. Interventional echocardiography is a new subspecialty that should be recognized, and specific training, including radioprotection training, should be part of the training course. Finally, interventional echocardiography is much more time consuming and carries more risk — in fact, the same risk as the interventionist (e.g. with radiation exposure and back pain issues with the leads) — than other echocardiography outside the cath-lab, and hence should be better reimbursed.

Nowadays, the link between imaging and catheterization has reached a peak, with the fusion of X-ray images and 3D-TOE images. The EchoNavigator™ system (Philips, Amsterdam, Netherlands) is a novel application, allowing the merging of these two independent imaging modalities to create a single integrated intuitive view in real time (Fig. 1 and Video A.1). Even better for the surgeon and the interventional cardiologist is the ability to touch the heart via a printed model of the heart defect, and to plan the intervention directly ex vivo [16]. Thus, a personalized heart model can be produced with 3D printing, which contributes to the preoperative evaluation, especially for a large ASD with rim deficiency, to identify appropriate candidates.

Hand-in-hand, pioneers in imaging and cardiac catheterization must continue their collaborative efforts to explore
the frontiers of interventional cardiac catheterization procedures.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.acvd.2018.03.003.

Disclosure of interest

The authors declare that they have no competing interest.

References


Figure 1. Fusion imaging with the EchoNavigator® during balloon calibration for atrial septal defect closure. Upper left: three-dimensional transesophageal echocardiography (3D-TOE), view from the left atrium. Upper right: 3D-TOE, view from the right atrium. Bottom left: echocardiography image in the same orientation as the C-arm gantry. Bottom right: fusion imaging between fluoroscopy and 3D-TOE.