Current perspectives

Intracardiac echocardiography. Do we need a new ultrasonographic window?

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Intracardiac echocardiography constitutes a new ultrasonographic window for the examination of the cardiovascular system, allowing a view of the heart and great vessels through a transvenous approach. Its use in interventional procedures, such as closure of secundum atrial septal defect and patent foramen ovale, transseptal puncture and radiofrequency ablation for arrhythmias is increasing sharply. The intracardiac echocardiography systems available today are of two types: mechanical and electronic scanning systems. Both enhance the visualization of the structures and of the endocardial surface inside the cardiac chamber where they reside, allowing the exclusive possibility of interaction between interventional instruments and the anatomic structures subjected to percutaneous treatment. The evolution of this methodology for the diagnosis and treatment of cardiac pathology requires the acquisition of new knowledge to ensure a correct and efficient use. The aim of this manuscript was to provide the clinical cardiologist with a complete overview on this topic.

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Introduction

Echocardiography has become the main imaging modality in clinical cardiology. In fact, transthoracic echocardiography may provide important information, both morphologic and functional, in real time. It is a non-invasive technique without complications, and may be performed at the patient's bedside with minimal nursing support. Its main limitations, including the anatomic acoustic barriers (ribs and lungs), obesity, thoracic wall deformity, pulmonary conditions and the limited possibility of posterior cardiac structure examination, may be overcome by transesophageal echocardiography, which provides excellent imaging of the heart and great vessels. However, transesophageal echocardiography is a semi-invasive procedure, not pleasant for the patient; it requires sedation and is not entirely free of pulmonary, cardiac or bleeding complications[1] (around 1%), and, at present, this methodology accounts for between 5 and 10% of the total volume of echocardiographic examinations. Recent progress has allowed the development of portable echocardiographic machines, to which a sonograph could be added, allowing the cardiologist to obtain a complete evaluation of the cardiovascular pathology at first contact with the patient ("the ultrasonic stethoscope")[2]. This great success of echocardiography in imaging diagnosis, achieved during the years, is now under comparison with other methodologies such as magnetic resonance[3] and multislice computed tomography[4], which have a higher diagnostic potential but also a higher cost. For this reason, it is difficult to predict what impact these methods will have in the cardiovascular field.

The growth of new technologies and techniques has brought echocardiography to a new threshold: intracardiac echocardiography[5]. This has become a new ultrasonographic window for clinical practice. With the introduction of every new technology, new perplexities arise because it is difficult to know its real value and clinical impact. However, historically speaking, new instruments and new methodologies have always caused a radical change in operative paradigms.

Because the real value of intracardiac ultrasound has not been fully tested in randomized trials, the main questions which a review on intracardiac echocardiography should provide an answer to are: what is the state of the art of the technology? when should it be used? where should it be used? who should use it?

What is the state of the art of the technology?

Nowadays, intracardiac imaging may be performed by using a transducer with mechanical or electronic scanning, mounted at the distal end of a catheter. This allows intracardiac echocardiography to be classified as a mechanical scanning or an electronic scanning system.

Mechanical scanning system. The mechanical probe, known as Ultra ICE^{TM}, was developed and is marketed by EP Technologies (Boston Scientific Corporation, San José, CA, USA). It was approved by the Food and Drug Administration (FDA) in June 1997. The Ultra ICE catheter, model 9900, consists of a central inner core and of a catheter body (9F) equipped, at its distal end, with a sonolucent window which incorporates a unique siliceous piezoelectric crystal with a frequency of 9 MHz. At its proximal end, it is equipped with a connector for the motor drive unit that allows rotation of the transducer and the transmission and reception of ultrasound waves. The central inner core consists of a flexible wire with a high torsion and rotation capacity that transfers to the transducer a circular movement with a speed ranging from 1600 to 1800 rpm. The resulting wave is propagated on a transversal plane, perpendicular to the long axis of the catheter, to create a two-dimensional image presented as a video tomographic session (radial at 360°) in real time on a dedicated review station, also used when performing intracoronary ultrasound (ClearView Ultra^{TM}, version 4.22 or higher, or Galaxy^{TM}, EP Technologies, Boston Scientific Corporation). This represents the use interface and allows modification of the image magnification, gray scale, luminosity and contrast as well as the storage of the images in a super-VHS videotape. Moreover, the catheter may be automatically withdrawn up to a maximum distance of 15 cm by a pullback device at a constant speed of 0.2-0.5-1.0-2.0 mm/s. The data so obtained may be stored in a personal computer (TomTec Imaging System, Unterschleinheim, Germany) which, in turn, provides accurate measurements and a three-dimensional reconstruction of the examined structures. In addition, it is possible to obtain a high reproducibility in spatial terms with less operator dependency, finding the same plane at successive studies with an error of just a few millimeters or even less. With the Ultra ICE catheter, the penetration depth is about 5.0 cm, but because the scanning is radial, the useful imaging field is actually about 10 cm, with axial and lateral resolutions of 0.27 and 0.26 mm respectively.

The Ultra ICE catheter, a single-use disposable device, is introduced through the femoral vein and advanced toward the right heart with an "over the wire" Convoy^{TM} 8.5F introducer (EP Technologies, Boston Scientific Corporation), available in several lengths and curves (distal curvature angle ranging from 0 to 180°). This allows the operator to navigate the catheter in the right heart chambers and to manipulate the distal portion of the catheter containing the transducer in various directions. Before insertion, the Ultra ICE catheter requires an exhaustive preparation including sterile apyrogenic water rinsing of the sonolucent camera to eliminate any air which otherwise could lead to a decreased imaging quality.

Electronic scanning system. The electronic probe, known as AcuNav^{TM}, was developed and marketed by Acuson Corporation (Mountain View, CA, USA), and was approved by the FDA in December 1999. The AcuNav catheter incorporates a single-use disposable crystal matrix (64 ceramic elements) arranged in a row, which forms a phase variant (or delay) in transmission and in reception ("phased array"); in this manner, it is possible to create a wavefront forming an acoustic lens focalized at a point called the acoustic focus. The AcuNav catheter may be interphased exclusively with an ultrasonographic Acuson machine to generate the acoustic waves and to process the information thanks to a multiuse connector (SwiftLink^{TM} Catheter Connector) that provides automatic catheter setting. The connector is the same for the Sequoia^{TM} and Aspen^{TM} echocardiographic machines, whereas the Cypress^{TM} necessitates its own connector. Regardless of the available echocardiographic machine, the catheter is 10F and has a length of 90 cm and does not require any preparation. It is introduced into the venous system by means of a standard 10.5-11F introducer and, as long as it is not an "over-the-wire" system, is placed in the desired position after strict fluoroscopic monitoring. The distal portion of the catheter may be manipulated in four directions on two orthogonal planes (left-right on a plane perpendicular to the imaging plane and anterior-posterior on the plane coincident with the imaging plane, at 160° in any direction, similarly to the transesophageal probe) to provide two-dimensional 90° vector images on a plane parallel to the long axis of the catheter. The main advantages of the electronic scanning system include the four-way maneuverability, the multiple frequency agile capability (from 5.0 to 10 MHz) allowing focalization at various depths (up to 15 cm) and the possibility of obtaining, during two-dimensional imaging, evaluations by the Doppler technique (pulsed, continuous, color and tissue), with a dynamic range of 30 to100 dB.

When should it be used?

Certainly, intracardiac echocardiography cannot be considered a first-line diagnostic methodology, and its use should be reserved for particular clinical situations in which it is necessary to obtain a better visualization of the cardiovascular anatomy and to guide interventional procedures in place of transesophageal echocardiography.

The transducer selection criteria depend on the procedure to be performed and on the structures to be examined, taking into account the advantages and disadvantages of both the mechanical and electronic systems (Table I).

Circumferential scanning with a mechanical transducer remains the simplest and least expensive approach to transverse section imaging reconstruction, with excellent resolution in the near field and poorer resolution in the far field, because it is not possible to focus the ultrasound. Moreover, artifacts, such as non-uniform distortion caused by friction between the inner central core and the internal surface of the catheter, are not usually found during intracardiac echocardiography as long as the catheter does not pass through tortuous segments.

Sector scanning with an electronic transducer provides some advantages, such as a larger and different field depth and the possibility of Doppler evaluation. The limitations of the electronic system are principally a decrease in lateral resolution that worsens with increased depth, the formation of side lobes responsible for artifact production on the images, the presence of reverberation observed in the first centimeter of depth and the phenomenon of partial or total cancellation of the electric impulses (echo drop-out) of structures localized perpendicular to the direction of exploration.

Therefore, it is evident that the mechanical system is preferable if morphologic and morphometric evaluations of the structures near the catheter (superior vena cava, right atrium, inferior vena cava) are required, whereas the electronic system is better when it is necessary to obtain morphologic and functional information on the contiguous structures (left atrium and pulmonary vessels). On the one hand, the main advantage of circumferential scanning lies in the possibility of evaluating the anatomy of the heart and great vessels in the transverse scanned plane, allowing successive evaluations in the oblique planes in an attitudinally correct anatomic orientation, with the left atrial structures localized laterally, to the left, and posterior to those of the right atrium, which are anterior. Moreover, this imaging presentation is comparable with those of other techniques, such as computed axial tomography and magnetic resonance. On the other hand, the main disadvantage of sector scanning is its ability to provide only oblique planes with respect to the thorax, so that the information obtained must be mentally reinterpreted since the orthogonal planes of the heart are differently aligned with respect to those of the body. Moreover, the anatomy represented by the intracardiac electronic scanning approach is unique and has a peculiar section not comparable to that of other methods, not even transesophageal echocardiography. Finally, as the technique has been in use for a shorter time, there is still confusion about how to obtain and represent these images.

All this is with regard to the circumferential scanning system, whose imaging planes are easily obtainable with less dependency on the operator ability than sector scanning at 90°, which is subject to important variations due to the individual anatomy, which is often altered by the underlying pathology.

When it is necessary to obtain biplanar images to guide and monitor an interventional procedure in the right atrium or on the atrial septum it is preferable to use a mechanical scanning transducer. In such a case, the mechanical intracardiac probe may be used in adjunct to conventional fluoroscopy, which shows the heart and great vessels on the coronal plane without depth, in order to obtain an image of the cardiac structures in the other basic planes: in fact, this imaging method is able to provide information both in the transversal plane of the thorax and on the longitudinal plane of the heart (i.e., on the thoracic parasagittal plane). From a practical point of view, intracardiac echocardiography with a mechanical transducer is particularly useful in the following interventional procedures: radiofrequency catheter ablation of the superior portion of the sinus junction in inappropriate sinus tachycardia[6], of the slow posterior pathway in atrioventricular nodal reentrant tachycardia[7], of the crista terminalis in ectopic right atrial tachycardia[8], and of the cavo-tricuspid isthmus in atrial flutter[9,10]; transcatheter closure of secundum atrial septal defect and patent foramen ovale[11] or transseptal puncture[12].

Table I. Main differences between systems.

Ultra ICE	AcuNav
FDA approval: June 20, 1997	FDA approval: December 15, 1999
Mechanical scanning system	Electronic scanning system
Unique siliceous piezoelectric crystal	Crystal matrix (64 ceramic elements)
9F over-the-wire catheter	10F non-over-the-wire catheter
9 MHz frequency	5.0-10 MHz frequency agile
Radial scanning at 360°	Sector scanning at 90°
Images on a plane perpendicular to the long axis of the catheter	Images on a plane parallel to the long axis of the catheter
Imaging field: 10 cm	Imaging field: 15 cm
Platform: ClearView Ultra, Galaxy (EP Technologies, Boston Scientific Corporation)	Platform: Sequoia, Aspen, Cypress (Acuson Corporation)
Single operator use	Two-operator use
Three-dimensional reconstruction	Doppler technique

FDA = Food and Drug Administration.

On the contrary, intracardiac echocardiography using an electronic transducer is superior only for the visualization of the left atrial structures (left auricle and pulmonary veins) from the right atrium, even though it is currently used exclusively to monitor the sizing balloon technique and device deployment during transcatheter closure of interatrial communications. Thus, it is particularly useful in guiding the radiofrequency transcatheter ablation procedure that implies the isolation of the pulmonary veins by creating circular lesions around their ostia[13-15], and for the evaluation of the flow variations in the pulmonary veins[16], pre- and post-procedure, in patients with atrial fibrillation. Moreover, other indications include transcatheter ablation of the ventricular outflow tract for ventricular tachycardia[17], the percutaneous exclusion of the left auricle for the prevention of cardiac emboli, percutaneous mitral valvuloplasty[18], and percutaneous septal ablation for hypertrophic cardiomyopathy.

In conclusion, the main clinical advantages of both intracardiac echocardiography systems are: 1) the short distance of the interrogated tissue from the transducer that allows optimal contrast between soft-tissue structures, 2) the relative homogeneous fluid path due to the uniform unidirectional backscatter of the red cell, 3) the easily and readily recognizable morphological changes of the cardiac anatomy during the procedure, 4) the limited fluoroscopic exposure time for both the patient and the physician, and 5) the good patient acceptance for a relatively prolonged time period. On the contrary, the drawbacks include: 1) no multiplanar capability, 2) the large catheter size that may limit its optimal use, and 3) the necessity of a dedicated system and disposable catheter that would be expected to add significant costs to the procedures.

Where should it be used?

Currently, intracardiac echocardiography should be considered an integral part of interventional percutaneous procedures in the cardiac catheterization laboratory and of vascular endoprosthesis implant procedures in the operating room.

The indications for intracardiac echocardiography at the cardiac catheterization laboratory or for electrophysiological interventions have been aforementioned. In the operating room, during vascular endoprosthesis implantation at the thoracic or subrenal aortic level, only the mechanical probe may be used to provide an exact evaluation of the lesion and to ensure that the expansion of the endograft is complete and symmetric.

Some authors have suggested the use of transesophageal echocardiography for monitoring thoracic endovascular procedures, even though the technique has important limitations which include: 1) a suboptimal echographic view, chiefly in patients with a "hostile" thorax or other causes of acoustic barriers; 2) a loss of continuity of radiologic imaging caused by the significant interference of the echographic probe in the fluoroscopic field; 3) a difficult visualization of the posterior aortic arch, due to the interposition of the trachea and the right bronchus between the esophagus and aorta; 4) a loss of topographic orientation due to the fact that the sectored scanning at 90° requires separate acquisitions of the descending and ascending aorta, and finally 5) a suboptimal endoprosthesis aortic neolumen evaluation caused by acoustic interference of the metallic components of the graft.

Because of all these difficulties, the authors have tested the clinical-diagnostic potentiality of the mechanical scanning Ultra ICE catheter for the evaluation of thoracic and complex abdominal aneurysms[19] in the operating room. In our experience, the echographic exam with a mechanical transducer is particularly useful for two main reasons: first, before the procedure, 1) to confirm the aortic pathology and the previous morphometric evaluation obtained at computed tomography or magnetic resonance, 2) to define the proximal and distal extensions of the aortic lesion documenting the transducer position on the fluoroscopic image with reference to a radio-opaque metric scale placed under the patient's back, 3) to morphologically identify the components of the vessel walls at the endoprosthesis deployment area with particular reference to the presence of calcium and the extension of the endoluminal thrombosis, and finally 4) to visualize the origin of vascular structures such as the left subclavian artery, the celiac trunk, the renal and internal iliac arteries, which may be clearly identified as distinct interruptions of the habitual circular aspect of the aorta or of the common iliac arteries; second, after deploying the prosthesis, 1) to identify the correct position of the stent graft, 2) to determine the complete and symmetric expansion of the endoprosthesis struts, 3) to evaluate the absence of any possible cause of flow limitation, and finally 4) to verify the patency of the main collateral branches. Thus, we are convinced that the contribution of intravascular echocardiography with a 9 MHz mechanical transducer to the aortic endoprosthetic procedure could become essential in the near future, significantly contributing to a reduction in the risk of acute and subacute graft occlusion and drastically decreasing the incidence of recurrent leaks from the prosthesis anchorage site in the aorta and iliac arteries.

Who should use it?

In view of the above discussion, intracardiac echocardiography is being routinely used in several intervention procedures in the catheterization-electrophysiology laboratory and in the endovascular surgical suite room. Its ability to allow the physician to program, to monitor and to immediately evaluate the interventional results has improved patient treatment and outcome.

Intracardiac echocardiography with a mechanical scanning transducer may be managed in a completely autonomous fashion by the same interventional team ("single operator use"), whereas the electronic scanning catheter has to be managed together with echocardiographer colleagues ("two-operator use"). In any case, the management of the intracardiac echocardiographic exam should depend on the interventional cardiologist, and both human and economic resources should be viewed in an integrated way with the clinical type of service offered, on the basis of the markers of training quality and interdisciplinary collaboration. This general principle concretely means that the direct performance of the intracardiac echocardiographic exam by the same interventional cardiologist using a mechanical probe responds to two kinds of exigencies by saving time and expense, whereas with respect to intracardiac echocardiography using an electronic probe the clinical echocardiographer and the echocardiographic machine should be reserved for diagnostic routine use.

The implementation of intracardiac echocardiography as a new method requires a development program with well-defined objectives that should be based on the availability of key resources, such as technical and scientific competence, and on the qualitative and quantitative levels of the operator. Unfortunately, intracardiac echocardiography has not yet been included in the curriculum of cardiologists in training, and there are no specific courses on this topic. We hope that in the near future intracardiac echocardiography may play a leading role in the training program of cardiologists with the support of scientific societies in order to establish the professional standard on this matter.

In the meantime, the minimum requirements for the performance and interpretation of intracardiac ultrasound should satisfy the general principles of the American College of Cardiology/American Heart Association clinical competence statement on echocardiography[20], that include: 1) skills in inserting and manipulating the catheter to obtain the required views, 2) knowledge of the physical principles of the echocardiographic image and instrument settings, and finally 3) knowledge of the anatomy, physiology and pathology of the heart and great vessels.

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