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Intracardiac Echocardiography – Technology and Clinical Role

Th. Bartel¹, G. Caspari¹, S. Mueller², R. Erbel¹

Transthoracic and transoesophageal echocardiography (TTE, TEE) are established standard approaches to diagnose a variety of cardiac diseases. Both techniques are limited, however, particularly in some clinical scenarios. Therefore, intracardiac echocardiography has gained acceptance, eg to guide certain interventional procedures such as catheter positioning and ablation. Up to now, all commercially available intraluminal ultrasonic devices were restricted to two-dimensional (2D) imaging. We discuss our first experience with and potential uses of a new ultrasonic transducer-tipped catheter device with unlimited echocardiographic capabilities. *J Clin Basic Cardiol 2002; 5: 133–7.*

Key words: coronary artery reactivity, programming, perinatal, birth weight

C onventional transthoracic echocardiography (TTE) is well known to be limited, particularly in patients with insufficient sound conditions. The transoesophageal echocardiographic approach (TEE) is well established to provide exceptionally high resolution images, particularly of the left atrial morphology, the mitral and the aortic valve as well as other important structures, which are partly inaccessible by TTE. TEE profits by immediate proximity of the oesophagus to the left atrium (LA) increasing its capability of Doppler flow assessment and functional analyses but, however, application is impeded during interventional procedures because of patients supine position.

Miniaturised ultrasound tipped catheter devices have been primarily introduced for use in blood vessels [1]. Intravascular ultrasound (IVUS) was then employed for imaging coronary arteries as well as peripheral vessels [2]. On the technical basis of IVUS, the development of intracardiac echocardiography (ICE) advanced in order to meet the demand for precise catheter placement in electrophysiological interventions. Thus, the progress in electrophysiology has been bound up with developing ICE.

Clinical Use of Conventional ICE

In electrophysiological interventional procedures, conventional ICE was used to guide the anatomic placement of the ablation catheter and to assess catheter-tissue contact [3]. Consecutively, particular lesions can be accurately targeted to specific anatomic structures guided by use of ICE. Moreover, lesion formation can be confirmed and lesion size and continuity identified. Immediate identification of complications and reduction in fluoroscopy time are other remarkable benefits of direct endocardial visualisation during radiofrequency (RF) catheter ablation [4]. With a frequency of 9 MHz ICE permits detailed identification of normal and abnormal cardiac anatomy with improved imaging depth. It is also of clinical utility for guiding interatrial septal puncture [5]. In contrast, the capability of ICE to differentiate mass from pectinate muscle in the left and right atrial appendage [6] does probably not justify employment of this invasive approach. Anatomical abnormalities being prone to affect RF ablation, as is narrowing of the superior vena cavaright atrium junction [7], the display can be beneficial in a variety of clinical scenarios. That also applies to the identification of distinct endocardial structures with excellent resolution and detail, including the crista terminalis, right atrium (RA) appendage, caval and coronary sinus orifices, fossa ovalis, pulmonary vein orifices, ascending aorta and its root,

pulmonary artery (PA), right ventricle (RV) and all cardiac valves. Display of these structures became possible with 9-MHz transducer tipped catheters [8].

However, all IVUS devices and IVUS based conventional ICE devices are not steerable and must be guided by a wire [9, 10]. That these devices are lacking in any Doppler capability must be considered the most important disadvantage for cardiovascular diagnosis. Therefore, functional analysis by use of intracardiac echocardiographic imaging had remained desirable but impossible for a decade. Nevertheless, IVUS had shown to be better than contrast angiography in the detailed assessment of coronary and peripheral arterial atherosclerotic lesions, arterial dissections and clots, aortic and pulmonary arterial disorders, and showing the effects and complications of interventional therapy in various vascular beds. Early experience with ICE suggested that this technique could evolve as a clinically useful method with diagnostic, monitoring, and guidance applications possibly leading to the conversion of catheterisation laboratories into integrated imaging, monitoring, and therapeutic stations. In addition, continuous monitoring could be possible in the critical care unit and in the operating room too [10].

Advanced ICE by Use of AcuNav[™]

The recently introduced multi-modal, phased-array transducer-tipped AcuNav™ catheter (Acuson Inc., Mountain View, California, USA) can visualize smallest anatomical details in 2D- and M-mode. Complete Doppler capabilities including pulsed-wave, continuous wave, colour flow, and tissue Doppler (TD) allow functional analysis for the first time [11]. An 11 Fr sheath is recommended to introduce the 10 Fr ultrasound catheter which is 90 cm long. The disposable catheter is equipped with a miniaturised 5 to 10 MHztransducer and can be navigated through the inferior vena cava (IVC) into the right atrium (RA), right ventricle (RV), and the pulmonary artery (PA). The 64-element vector phased-array transducer permits longitudinal scans and provides a 90° sector image with tissue penetration to a depth of up to 12 cm. A certain expertise is required to orient oneself inside the heart and to visualize the cardiac structures adequately. Biplane fluoroscopy is recommended to safely advance the bidirectionally steerable catheter without a guide wire. In 10 animal experiments (6 Beagles, 4 pigs) we did not observe any vascular perforation, neither during transarterial nor transvenous application. In one experiment the tip of the catheter turned over when the device was advanced. The catheter required straightening in the right atrium prior to

From the ¹Department of Cardiology, University Essen, Germany and the ²Department of Cardiology, University Innsbruck, Austria. <u>Correspondence to:</u> Thomas Bartel, MD, Department of Cardiology, University Essen, Hufelandstr. 55, D-45122 Essen, Germany; e-mail: thomas.bartel@uni-essen.de removal. The European Community approval (CE-mark) has been recently granted.

Visualising the Aorta and its Branches

This technology has potential benefits for the evaluation of aortic dissections and will be useful to optimize stent placement in these cases. In our experience, transvenous and transarterial echocardiography are capable of in-detail imaging of the entire aorta. The morphology of the aortic



Figure 1. Right renal artery viewed from the inferior vena cava including color Doppler flow and spectral Doppler analysis. Ao = aorta; IVC = inferior vena cava



Figure 2. Superior mesenteric artery shown by intravascular color Doppler

wall, including details of the intima, media, and adventitia, can be visualised. Aortic and branch flows are depicted, including coronary, subclavian, carotid, renal, and visceral artery flow. The resulting image resolution and Doppler signal quality are much superior to conventional TTE and even to TEE examinations [12].

Only the transarterial approach seems to permit adequate estimation of the aortic compliance. Both the left and right coronary arteries are visualized, their flows displayed. In addition, the coronary flow reserve of the proximal left anterior descending coronary artery is measured [12]. From the transvenous window, the catheter provides unique visualisation of the abdominal aortic branches: renal (Fig. 1) as well as superior and inferior mesenteric arteries (Fig. 2). To accomplish this the catheter is first turned and then straightened to aim the transducer at the neighbouring aorta. This probably helps to protect side branches during aortic stent implantation.

Assessing the Cardiac Chambers and Pulmonary Veins

With the catheter in the RA and retroflexed into a short-axis orientation, the interatrial septum, especially the fossa ovalis, and the septum primum can be very clearly displayed (Fig. 3). In fact, patent foramen ovale (PFO) and atrial septal defect (ASD) (Fig. 4) can be demonstrated and device closure monitored (Fig. 5) [13]. Beside this, both atrial appendages and the left and right pulmonary veins were shown in a unique quality and flows were registered. Similar benefits have been reported for radio-frequency ablation and also for diagnostic electrophysiological procedures [14]. Intracardiac echocardiography seems to be a very useful tool to identify critical landmarks of the heart important for orientation and electroanatomical cardiac mapping. One of these landmarks is the fossa ovalis - intracardiac echocardiographic guidance facilitates transseptal puncture by precisely imaging the fossa ovalis (Fig. 3). Since its anatomy is variable, the Brockenbrough needle may point to the muscular septum possibly leading to a perforation by use of fluoroscopy only. Other potential applications of this technique include reduction in fluoroscopy time, evaluation of radio-frequency



Figure 3. Left atrium, left atrial appendage, and left pulmonary veins demonstrated with the AcuNavTM-catheter being placed in the right atrium and lined up with the interatrial septum. Ao = aorta; LAA = left atrial appendage; LA = left atrium; LLPV = left lower pulmonary vein; LUPV = left upper pulmonary vein; RA = right atrium

lesions, and confirmation of catheter-tissue contact prior to ablation therapy.

Very clear TD images also allow quantitative LV wall motion analysis. To permit optimal analysis of left ventricular (LV) function from short axis or parasternal long axis views, the AcuNav[™] catheter should be pressed against the lateral RV wall. If this is not done, motion and Doppler analysis might be impaired and the movement pattern could become erratic as the catheter floats freely inside the cardiac chamber (Figs. 6 and 7). LV longitudinal planes can be obtained from inside the RA by slightly anteflexing the catheter and by turning it posteriorly; the catheter is strongly anteflexed to show the RV. The resulting clarity of the imaged endocardial contours including trabeculae and papillary muscles (Fig. 8) cannot be achieved with TTE or TEE. Epicardium and pericardium can be easily distinguished if they are not fused.



Figure 4. Color-Doppler image of a left-to-right shunt due to a small ASD. Ao = aorta; LA = left atrium; RA = right atrium



Figure 5. Device closure of a patent foramen ovale guided by intracardiac echocardiography with the AcuNavTM-catheter placed in the right atrium and retroflexed into a short-axis orientation. Typical attitude before the AmplatzerTM-PFO occluder is removed from the cable. LA = left atrium; RA = right atrium; 1, right umbrella of AmplatzerTM-PFO occluder; 2, left umbrella of AmplatzerTM-PFO occluder



Figure 6. Rhythmic motion of the AcuNav[™]-catheter within the right ventricle causes pseudoparadoxical motion of the interatrial septum. IVS = interventricular septum; LV = left ventricle; LVPW = left ventricular posterior wall



Figure 7. The AcuNav[™]-catheter is now pressed against the lateral RV wall avoiding its motion within the right ventricular cavity. LV = left ventricle; RV = right ventricle

Imaging the PA and the Cardiac Valves

Using 4-way tip articulation and with the transducer in the RA, high quality near-field images can be acquired and the Doppler flow patterns through all 4 heart-valves analysed. To visualize the tricuspid and the mitral valve the catheter is manoeuvered in the same fashion as for the ventricles. To adequately image the aortic valve, the catheter is straightened in the RA and slightly anteflexed. Good pulmonary valve visualisation is achieved with the catheter in the RV and the transducer aimed at the right ventricular outflow tract. Therefore the catheter is first positioned at the roof of the RA



Figure 8. The right ventricle viewed with the AcuNav[™]-catheter pressed against the roof of the right atrium. LV = left ventricle; RA = right atrium; RV = right ventricle



Figure 9. Left and right pulmonary arteries viewed with the AcuNav^T-catheter in the pulmonary trunk. IPA = left pulmonary artery; rPA = right pulmonary artery; PT = pulmonary trunk

looking down to tricuspid valve, than strongly anteflexed and cautiously advanced into the RV. Even subtle structural disorders can be precisely analysed prior to surgical valve repair or even intraoperatively, which would be challenging with TEE. The ultrasound-tipped catheter can also be advanced with caution into the pulmonary trunk to inspect the left and right PA from inside the vessel (Fig. 9) [12]. This technique can directly show thrombi in the central pulmonary arteries in the case of PE.

Clinical Implications

The percutaneous transluminal multi-modal ultrasound technique can be considered a diagnostic approach which evolved from conventional echocardiography and IVUS. The general trend towards increasing use of corrective and reconstructive vascular and cardiac surgical as well as percutaneous interventions makes this new method destined to become the tool of choice to guide and optimise those therapies: Views from inside the IVC can be used to guide abdominal aortic stent implantation and surgical therapy. Especially changing flow dynamics within the false lumen of dissecting aneurysms of the abdominal aorta can be evaluated after interventional or surgical closure of a proximal entry. Transvenous imaging also shows additional promise for the detection of renal artery and stenoses including functional assessment during and after surgical treatment.

In cases of an ASD or PFO, ultrasonographic cardioscopy can provide assistance with device implantation, reduce procedural and fluoroscopy time, and limit the risk by showing the specific anatomic relationship between occluder and surrounding structures. We expect that this new method will also permit successful guidance for interventional closures of other congenital heart defects such as patent ductus arteriosus, ventricular septal defects and arterio-venous fistulas. Due to the combination of high image resolution and Doppler analysis, constrictive pericarditis may be distinguished from restrictive dysfunction - which is difficult to do with conventional echocardiographic approaches. In cases of endocarditis, the AcuNavTM catheter opens up new avenues to clearly differentiate strands from vegetations and to diagnose endocarditis if TEE fails to make this distinction. Intravascular and intracardiac thrombi can also be imaged, facilitating their percutaneous endoluminal disruption. It is envisioned that the development of devices which integrate ultrasound transducers into interventional tools, will be a major stepping-stone towards a new generation of combined diagnostic and therapeutic tools for intravascular therapy.

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