
Volume 14 - Issue 1, 2014 - Cardio Spotlight

Echocardiography as a Multimodality Cardiac Imaging Technique

Author



Prof. Petros Nihoyannopoulos MD, FRCP

Professor of Cardiology,

Imperial College London

Hammersmith Hospital

London, UK

Historical Note

The year 2013 was the 60th Birthday of the founding of Echocardiography and the 160th anniversary since the death of Johann Christian Doppler (1803-1853). Those two events marked modern cardiology by not only shaping up a more accurate diagnosis of heart disease but also guiding patients' management. Echocardiography has to be included among the top 10 greatest discoveries dating back to the discovery of piezoelectricity by Pierre and Jacques Curie (Curie and Curie 1880). Echocardiography was conceived in 1953 when Inge Edler, a physician from Lund University in Sweden, together with Hellmuth Hertz, a Swedish physicist and the son of a Nobel laureate in physics, performed the first human echocardiogram, which they called Ultrasound Cardiography (UCG) (Edler and Herz 1954). They used a shipyard sonar machine (Siemens Co, Germany) in Malmö that was used to detect structural flaws in boats, called 'ultrasonic reflectoscope', now in the Museum of Medical History in Lund. The images of the heart were crude and the knowledge of what it represented false. In October 1953, Edler and Hertz recorded the first 'Ultrasound Cardiogram' and published their findings the following year (Edler 1955; Edler 1956). Figure 1 shows one of the first echocardiographic recordings of the heart some 60 years ago. Edler went on to be a pioneer in echocardiography, while Hertz went on to invent the inkjet printer. There was little progress for a decade until 1963, when Harvey Feigenbaum, frustrated by the numerous limitations of cardiac catheterisation and angiography, borrowed an unused echoencephalography machine to scan the heart, and noticed that cardiac images could be recorded. He became the first person to describe pericardial effusion (Feigenbaum et al. 1965). By substituting 'cardio' with 'encephalo' it was this machine's origins that gave the name 'echocardiography'.

In the meantime, in 1956 in Japan, Yoshida and Nimura were the first to apply the Doppler principle to cardiac recordings, but the resulting signals were wrongly interpreted as being caused by movements of the heart muscle and the valve leaflets. No signal was attributed to blood flow, and consequently the method was of little interest to cardiologists. It was not until 1969 that during the first World Conference of Ultrasonic Diagnosis in Vienna I. Edler and K. Lindstrom presented their ultrasound Doppler studies, including the first 40 clinical cardiac Doppler recordings for the evaluation of aortic and mitral regurgitation (Lindstrom and Edler 1969). Although cardiac Doppler was described fairly extensively in Europe, it was not until Holen (Holen and Simonsen 1979) and Hatle (Hatle and Angelsen 1985) showed that accurate haemodynamic data could be determined with Doppler ultrasound that Doppler revolutionised the non-invasive assessment of cardiac haemodynamics in clinical practice. Echocardiography and Doppler, better termed as 'Echocardiology' have expanded enormously and become an integral part of the diagnostic pathway for every patient with known or suspected heart disease.

Never before has the pace of innovations in echocardiography been so swift. Echocardiography today has been revolutionised alongside competition from other imaging modalities, such as cardiovascular magnetic resonance imaging and computer tomography. It is by far the most used cardiac imaging test, with over 23 million echocardiographic studies performed in the U.S. annually and 2.5 million stress echoes. The most common use is the assessment of ventricular function, valve disease and the haemodynamic assessment using Doppler, so that it has become essential in management of all forms of heart disease. The daily cardiac haemodynamic assessment is now based on Doppler haemodynamics for valve disease and diastolic function, while invasive haemodynamics are only reserved for when clinical discrepancies occur. That saves patients from unnecessary and potentially hazardous ionising radiation.

During the 1970s and 1980s, invaluable collaboration between engineers and physicians culminated in the development of two-dimensional

echocardiography, Doppler echocardiography, colour-flow Doppler echocardiography and transesophageal echocardiography. In Europe Bom et al. (1973) developed a multi-element transducer to provide electronic linear grayscale scans of real-time two-dimensional cardiac images. More and more equipment manufacturers recognised the importance of developing their own transducers to be better matched with their equipment to provide high frontend compatibility and further improving image quality.

From the initial poorly understood M-mode echocardiographic recordings of the left ventricle, two dimensional echocardiography added spatial resolution to the imaging of the heart, and more clinicians were able to appreciate the anatomy and function of the heart, so that the method was adopted even by the most sceptical clinicians. Figure 2 is a four-chamber projection of the heart from the apex, clearly demonstrating the relative chamber sizes and valves. Notice the presence of an organised apical thrombus at the apex (arrow). However, while imaging quality continued to improve, two-dimensional echocardiography could not always match the clarity of some of the cardiac magnetic resonance imaging as it entered the clinical arena and some sceptics thought that cardiac MRI was the reference technique and that echocardiography was a technique of the past. How wrong they were!



Figure 2.
Two-dimensional echocardiographic image from the apical four-chamber view depicting the left ventricle with an organised apical thrombus (arrow)

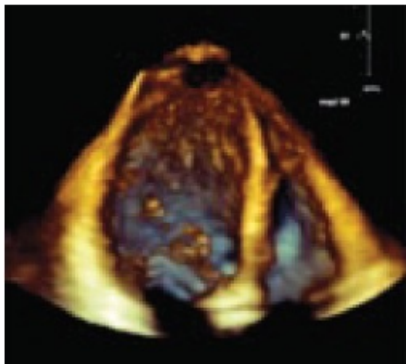


Figure 3.
Three-dimensional echocardiographic image from the apical four-chamber view depicting the left ventricle. Note the difference from figure 2 with the left ventricular trabeculations and surface clearly identified.

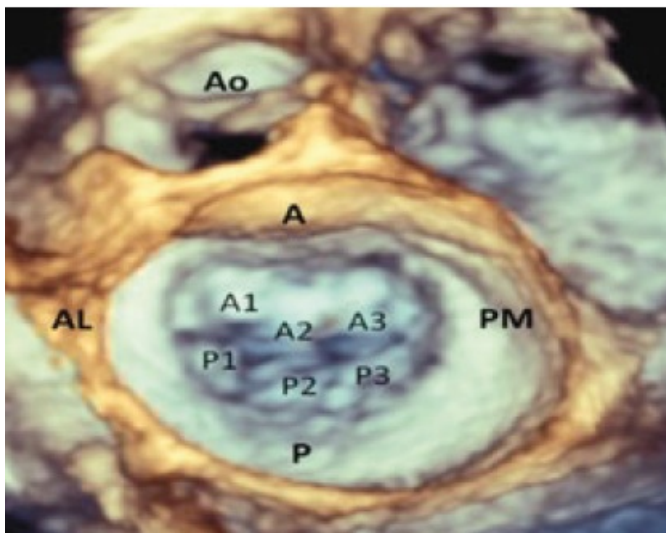


Figure 4. Transoesophageal surgical view of the mitral valve. Superimposed is the mitral leaflet segmentation. A=Anterior, AL=anteriorlateral commissure, Ao= aorta, A1 anterior leaflet lateral segment, A2= anterior leaflet middle segment, A3= anterior leaflet medial segment, P=posterior, PM= posteromedial commissure, P1=Posterior leaflet lateral segment, P2=posterior leaflet middle segment, P3=posterior leaflet medial segment.

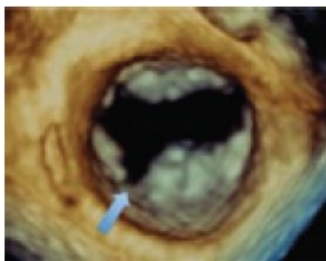


Figure 5. (Left) Transoesophageal surgical view of the mitral valve leaflets depicting the anterior leaflet and the posterior leaflet. Note the deep cleft identified in the region of P3 (arrow).

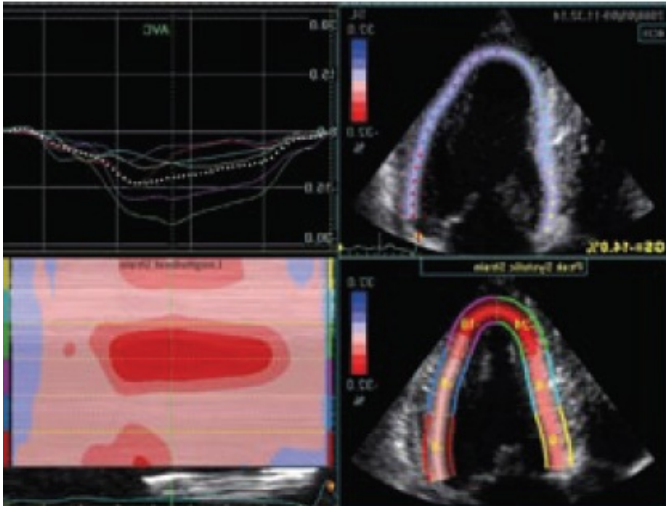


Figure 6. (Right) Two-dimensional speckle tracking of the left ventricle from apical four-chamber projection (as in figures 2 and 3). Top left depicts the tracking of all left ventricular walls (septal, apex and lateral walls). The value of -14% implies that the global strain (GS) is markedly reduced. Bottom left shows in colour coding the regional segmentation of the left ventricle in 6 segments with the respective strain values. Note that the lateral wall has the lowest strain values corresponding to myocardial fibrosis. Top right shows the strain values of each segment throughout the cardiac cycle. Bottom right is a colour-coded map of the longitudinal strain of the entire left ventricle from apex to base throughout the cardiac cycle.

The Present

Technology in echocardiography, like progress, is always changing, and for the better. The wide variety of transducers, frequencies, and applications that are available today for the echocardiographer is unlimited and will be so in the foreseeable future. New technologies such as tissue Doppler and speckle tracking are getting established while improving three-dimensional echocardiography image clarity is dominating technological development at a breathtaking speed so that sub-specialising on the various echocardiological modalities is becoming necessary. Figure 3 depicts an apical four-chamber projection of the heart with real-time three-dimensional imaging. Note that endocardial trabeculations are clearly visualised so that the heart looks more like a real anatomic specimen. These type of images are now routine in clinical practice.

Technology has responded to new clinical challenges with the explosion of interventions for structural heart disease, so that echocardiography with real-time 3D transoesophageal echocardiogram (TOE) has become indispensable in a modern cardiac catheterisation laboratory and cardiac operating theatres. Guidance for therapeutic procedures is now so routine that a new subspecialty in echocardiography has emerged, that of interventional echocardiography (Zamorano et al. 2011). Dedicated individuals need now to be familiarised with the procedures and communicate their results with the interventionalist. Procedures like mitral clip cannot be performed without TOE guidance, while TOE during transcatheter aortic valve implantation (TAVI) has become indispensable both for a more accurate assessment of the aortic annular diameter, the positioning the TAVI valve, and the early detection of complications. Figure 4 depicts a surgical view from the transoesophageal approach of the mitral valve, with the respective description of the Carpentier's segmentation of the anterior and posterior leaflets in three equal thirds.

Transoesophageal three-dimensional echocardiography has revolutionised the visualisation of the mitral apparatus on the beating heart. This has led to the better understanding of the mechanism of mitral regurgitation, and facilitates the choice of methods of treatment, particularly as more and more options become available, both in terms of surgical repair and also in transcatheter mitral clip placement. Never before has the mitral apparatus been seen and understood so well in the beating heart (Marsan et al. 2009). Mitral regurgitation can arise from a variety of mechanisms and may occur in combination. It is traditionally described by Carpentier's classification based on leaflet motion (normal motion, prolapse or restriction of a leaflet segment). The location and extent of abnormal leaflet motion guides the various treatment options (Grapsa et al. 2012). An accurate description of the mechanism of valve failure is therefore required to predict the complexity of techniques needed to repair the valve and hence the likelihood of achieving a successful mitral repair. Figure 5 is a surgical transoesophageal view from a patient put forward for a clip procedure, but three-dimensional imaging detected an unpredicted deep cleft of the posterior leaflet (arrow), which was prohibitive for a successful clip repair, and the patient had to be surgically repaired.

Assessing Myocardial Function

Cardiovascular medicine is changing. It is progressively becoming more and more disease-based for diagnosis and therapy with the

development of multidisciplinary meetings that are often image-guided. Some of the early changes have been noted in heart failure, coronary artery disease, pulmonary hypertension and cardiomyopathies, with the development of specialised clinics where imaging plays a pivotal role. Emphasis has been put on detecting preclinical disease and adopting prevention strategies. The development of genomics and proteomics in diagnosis has revolutionised the understanding of the disease regulation and development, but has not replaced the pivotal role of imaging. Measurement of ejection fraction has dominated clinical decision making for decades. While widely accepted that it is subjected to severe limitations due to cardiac loading conditions, speckle tracking echocardiography and deformation imaging have emerged to better assess and quantify ventricular contraction (Mor-Avi et al. 2011). No other imaging modality can match the detailed assessment and quantitation of myocardial function globally as well as regionally both in systole and diastole in such high time resolution. New outcome data are rapidly accumulating in all sorts of clinical scenarios (Ersbøll et al. 2012; Olsen et al. 2011). New measures such as the global longitudinal strain and also radial and circumferential strains are entering the clinical routine. Figure 6 is from a patient with hypertrophic cardiomyopathy, where speckle tracking imaging identifies reduced regional and global myocardial contraction despite a normal ejection fraction. Studies have shown that where strain measurements are significantly reduced, they correspond to areas of myocardial fibrosis seen by cardiac magnetic resonance imaging (Urbano- Moral et al. 2013).

We have new challenges looming, however. As machines are getting bigger and better, providing more information than ever before, others are becoming smaller and cheaper, potentially available to all. While the world of echocardiography is still coming to terms with these new systems, the small hand-held echo machines are rapidly becoming smaller, pocket-size, with ever improving image quality. While this can help in training junior doctors and doctors beyond cardiologists, they will require some further training. There is no doubt that those pocket-size devices will be a useful complement to the clinical examination and supplement to the good old stethoscope (Panoulas et al. 2013), but will not replace the larger, more comprehensive systems.

The Need for Regulating Echocardiography

One of the big problems of echocardiography in the past, not applicable to other imaging modalities, was the lack of a regulatory body to ensure training and quality control. Unlike nuclear medicine and radiology that tightly control MRI and nuclear imaging modalities, echocardiography was (and still is) open to everybody in a very cost-beneficial way. This almost guarantees clinical disasters when performed by the wrong hands. Not surprising, therefore, when people not appropriately trained perform echocardiographic examinations in an uncontrolled fashion, this is diminishing the standards of the technique. Consequently, several countries have established local certification programmes, some more rigorous than others. For this reason, the European Association of Echocardiography established universal accreditation standards (Fox et al. 2007), in order to standardise the quality of echocardiographic examinations across Europe.

Echocardiography performed in well-organised departments provides, de facto, a high standard and comprehensive description of the cardiac anatomy and function. All imaging techniques, from echo to cardiac MR (CMR) and nuclear are 'operator-dependent' and are as good as the person who drives them.

It is a fallacy to believe that nuclear or CMR methods are more 'objective' than echocardiography. It is the openness, unregulated and wide use of echocardiography by non-experts that occasionally give a bad reputation to the technique. The issue of training is of pivotal importance in every aspect of life, including medicine, and regulatory bodies have been set up in order to safeguard the patient.

The European Association of Echocardiography has put in place an accreditation process with an exit examination for all potential echocardiographers, doctors and scientists alike. This is now widely accepted as the European standard and promoted by the European Society of Cardiology, and individual member states, and national Societies, such as the Hellenic Cardiological Society are called to adopt it. While this is not currently linked to reimbursement, it will eventually become a requirement, and will help to improve training and delivery of echocardiography services nationally.

The Future

The future of echocardiography is bright. Investment in research and development has doubled over the past five years and technological innovations are put into clinical practice at such a speed that it has become very difficult to follow, even for dedicated echocardiographers. There is now sub-specialisation in echocardiography by contrast experts, deformation imaging experts, transoesophageal and stress echo experts and three-dimensional experts, with the latest subspecialisation by interventional echocardiographers. It is very difficult for a single person to be expert in all those modalities, unless they operate in a well-developed and organised department with good technical support available for all modalities. A new breed of 'Academic echocardiologist' is appearing, who devotes teaching and research time, as opposed to simple application of the technique as a clinical tool.

The trend in imaging is the development of the study of ventricular function and the non-invasive imaging of the coronary arteries, while the traditional perfusion methods are rapidly outmoded. The cost of ionising radiation by the traditional nuclear modalities, as well as the new multi-sliced computer tomography will always be a prohibiting factor in future applications and lead to their possible demise, while echocardiography will always remain the first choice in cardiac imaging.

Cardiac magnetic resonance imaging is rapidly entering routine clinical practice, but its high running cost prohibits its routine use. When Magnetic Resonance Angiography (MRA) becomes reality, it will certainly be a major breakthrough in clinical cardiology, but it will be costly and any healthcare system will not afford its wide use.

Echo and CMR are the imaging modalities of the future and are complementary, with echo being the most cost-effective and patient-friendly examination, and CMR the high end of cardiac imaging for tissue characterisation. During the next decade we will enjoy the explosion of new, more sophisticated echo and CMR modalities to ultimately benefit our patients.

Conclusion

Echocardiography has come a long way over the past 60 years and is now the prime and most-matured diagnostic cardiac imaging modality. Its non-invasive nature, which does not require ionising radiation, puts it in the forefront of cardiac investigations and has become essential in the management of heart disease in almost cost-effective manner.

Published on : Sat, 8 Mar 2014