Echocardiography has become an integral part of modern cardiology, and parameters measured by echocardiography are enshrined in guidelines as components of clinical decision-making in the management of heart failure, valve disease and arrhythmias. This review will explore four modalities which will underpin the future of echocardiography—the hand-held machine, quantification, three-dimensional imaging, and contrast. Finally, we will explore the implications of the new financial milieu for the selection of cardiac imaging modalities.

It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity...—Charles Dickens, A Tale of Two Cities

Echocardiography was born more than 50 years ago. It has become an integral part of modern cardiology, with central roles in the assessment of ventricular size and function, the diagnosis and evaluation of valvular disease, investigation of chest pain, possible cardiac emboli, and congenital heart disease. Parameters measured by echocardiography (e.g. dimensions, ejection fraction) are enshrined in guidelines as components of clinical decision-making in the management of heart failure, valve disease, and arrhythmias. Moreover, echocardiography is relatively simple, inexpensive, and obtainable in the office or bedside. The technique continues to evolve and, in particular, has benefited from the revolution in computing which has brought increasing processing power and increasing miniaturization.

Yet at the same time, echocardiography seems to be in risk of decline. Practitioners of echocardiography are becoming specialists in cardiac imaging and the learning of newer modalities is diluting training time in echocardiography. Together with the continuing migration of the technique to non-cardiovascular specialists, this process may lead to a lower average level of expertise among practitioners of the technique than at any previous stage. This review will explore four modalities which will underpin the future of echocardiography—the hand-held machine, quantification, three-dimensional imaging, and contrast. Finally, we will explore the implications of the new financial milieu for the selection of cardiac imaging modalities.

The miniaturization of echocardiography and the hand-held machine

Within the last two decades, the standard laboratory echo machine has shrunk from the size of a household refrigerator to potentially the size of a laptop computer (Figure 1). The most recent advance has been the development of a truly hand-held device which may be carried within a coat pocket. Such devices, retailing for <US$10 000, offer diagnostic-quality two-dimensional (2D) images with simplified colour Doppler and will become an adjunct to the physical examination.

These devices will have most to offer in the setting of ischaemic heart disease and heart failure (Figure 2). In ischaemic heart disease, echocardiography has been shown to be of value at all stages of the progression of the disease, ranging from acute chest pain presentations, confirmation of acute infarction, acute infarct complications, and the evaluation and management of chronic ischaemic heart disease. The integration of echocardiography and clinical decision-making is well illustrated by the use of the test in patients presenting with chest pain. Two-dimensional imaging obtained during pain or shortly thereafter has a negative predictive value of ~95% for the identification of infarction, with similar sensitivity for patients presenting with documented infarction. In heart failure, the use of echocardiography is pivotal in treatment selection and is complementary to the measurement of natriuretic peptides for the assessment of volume status—arguably one of the
The greatest challenges in heart failure management and one that directly impacts re-admission to hospital and therefore cost. Indeed, the use of echocardiography has been shown to improve outcomes in heart failure. Many of these applications do not occur in the echocardiography laboratory, but rather in physicians’ offices and the emergency room. The availability of high-quality, inexpensive hand-held devices will strengthen clinical decision-making.

The migration of echocardiography from the echocardiography laboratory to the clinician at the bedside will bring challenges with respect to training and quality control. Despite the technical feasibility of image acquisition with appropriate equipment, limited training appears insufficient to obtain the optimal benefit from this technique. It seems likely that there will be increasing requirements for formal training in echocardiography for potential users of the technique among emergency room and intensive care physicians, analogous to that provided during cardiology training. There is a precedent for such a training strategy among anaesthesiologists becoming trained in transoesophageal echocardiography.

The availability of relatively inexpensive, portable echocardiography machines may have a major impact on the identification and management of cardiac disease in the developing world. The ability of high-technology echocardiography to operate in a low-infrastructure environment (even with battery and solar power where mains electricity is not available) is unique among the imaging techniques. Already, a landmark study in Mozambique and Cambodia has documented a 10-to-15-fold increase in the identification of rheumatic heart disease with echocardiographic rather than clinical screening. As the epidemics of hypertension and obesity extend to the developing world, the ability to identify and characterize left ventricular (LV) dysfunction will permit the better selection of patients for preventive and therapeutic strategies.

Image quantification and the end of subjective interpretation

Automation and quantitation will be vital steps in supporting the interpretation of less expert (and less frequent) users of echocardiography. The subjective assessment of echocardiography is a well-recognized limitation which brings with it the need for formal training—especially in wall motion analysis—as well as variation between readers. This has been improved, but not avoided, by modern technical developments and standard guidelines for interpretation, and experience from nuclear cardiology suggests that quantitation will be the next step to reduce variation in interpretation (Figure 3).

The availability of a simple quantitative parameter to support the clinician’s interpretation of resting echo images would be a major step forwards. Although several quantitative techniques have been investigated, the assessment of myocardial strain appears currently to be the most feasible. This technique was initially based on tissue Doppler, with attendant concerns regarding noise and angle dependence. However, these concerns have been
addressed by the development of speckle-tracking techniques that permit these measurements to be performed on grey scale images. The development of accurate regional quantification is likely to be specifically beneficial to the evaluation of the coronary disease patient. Echocardiography has been shown to efficiently stratify patients presenting with acute chest pain. The absence of resting wall motion abnormalities in pain or shortly after resolution of pain identifies patients at low risk, and the prognostic content of this information is analogous to the results of SPECT imaging. Figure 4 illustrates the application of 2D strain analysis to the evaluation of resting function.

Similarly, there is a low probability of events in the absence of ischaemia in patients undergoing stress echocardiography.

Figure 3 Agreement between observers at various stages in standardization of SPECT and echocardiography.

Figure 4 Resting echocardiography showing antero-apical hypokinesis in the patient with chest pain, including the use of two-dimensional strain to identify the site and extent of abnormal motion.
Figure 5  Stress echocardiography showing inferior ischaemia in a patient after infarction (the biphasic response on the loop display is subtle). This can be found in the online supplementary data. The diagnosis of ischaemia is supported by strain and strain-rate the apical and basal segments of the inferior wall and septum showing delayed contraction on strain rate and reduced strain. A right coronary lesion was identified at angiography (lower panel).
either after an acute event or with chronic IHD.\textsuperscript{20} Again, this represents another area where quantification of myocardial deformation may be useful, and indeed, there is an evidence base to support the use of deformation assessment for the detection of viable myocardium (Figure 5),\textsuperscript{21} and normal ranges have been defined for resting function.\textsuperscript{22} At present, however, fundamental issues of feasibility, reproducibility, and especially variation between deformation measurements using different equipment\textsuperscript{23} are all limitations to the widespread adoption of deformation measurements. Technical advances will resolve these limitations, but currently most clinicians view this is a work in progress.

New methods for the assessment of myocardial function may also facilitate the detection of subclinical myocardial changes in non-coronary heart diseases. The ongoing adverse outcome of heart failure has heightened interest in the detection of early LV impairment, which may progress to heart failure.\textsuperscript{3} Moreover, the potential of the new echocardiographic techniques to permit this assessment in the clinic may facilitate the detection and management of these patients. Likewise, the same miniaturized machines may be used to identify early vascular disease, with implications for the selection of patients for primary prevention of atherosclerosis.\textsuperscript{24}

Three-dimensional imaging for quantification and display

Since its inception over 25 years ago, 2D echocardiography has offered real-time imaging in standard imaging planes. However, the portrayal of a three-dimensional (3D) object in two dimensions may lead to off-axis images, with adverse consequences on LV measurements (Figure 6).\textsuperscript{25} It is perhaps insufficiently recognized that the test–retest variability of 2D echocardiography is high, so that the smallest change of ejection fraction that is detectable with 95% confidence is 11%.\textsuperscript{26} Similarly, the smallest change in LV mass that is detectable with 95% confidence (59 g) exceeds the 20–40 g change in LV mass/year in antihypertensive trials.\textsuperscript{27} Three-dimensional imaging has provided a more accurate index of global LV size and function, as well as an intuitive 3D display which has been shown to be of value in the assessment of mitral valve disease (Figure 7), ASD closure, and off-pump surgery.\textsuperscript{28} This attribute of 3D imaging may overcome the difficulties that tomographic imaging can impose on communication with referring physicians and surgeons.

The eventual goal of 3D imaging will be to provide a series of 3D data sets, minimizing imaging time or even obtained remotely. At present, the image quality provided by 3D data sets does not compete with 2D imaging on the basis of either temporal or spatial resolution, with the result that diagnoses may be missed by the interrogation of 3D data sets alone.\textsuperscript{29} It seems likely that technological advances will remedy these shortcomings, permitting acquisition of a 3D data set, with offline processing to provide a series of 2D data sets independent of the expertise of the acquiring sonographer.

Contrast echocardiography

The role of contrast agents in the future of echocardiography is less certain than it was only a few years ago. These compounds are currently being used for LV opacification, but they have been persistently underutilized and this has not been helped by safety concerns—largely unsubstantiated—expressed by regulatory bodies. The conditions imposed as part of the ‘black box’ warning imposed by the United States Food and Drug Administration have now been relaxed.
Despite data showing that myocardial contrast improves the accuracy and prognostic value of stress echocardiography, the use of microbubbles for the assessment of myocardial perfusion remains an 'off-label' application. The regulatory approval of two new agents has been declined for safety and/or efficacy reasons, with the approved agents being a decade old. Thus, despite the promise of these agents for facilitated thrombolysis, gene delivery, and for targeted imaging for the detection of thrombi and inflammation, the future of this field remains uncertain.

**Economics of echocardiography**

Financially, echocardiography is a victim of its own success. Growth continues at 8–10% per year in most countries and payors are (legitimately) asking who benefits from this increasing expenditure, the growth of which exceeds the overall growth of medical services. The recently published appropriateness criteria represent the first steps towards avoidance of the cost of unnecessary studies, and future studies need to be directed at defining when imaging is not required. Like many imaging techniques, echocardiography has failed to develop an effective evidence base for defining its cost-effectiveness, and the development of this evidence must become a part of the future of echocardiography.

The features that favour the growth of echocardiography will have to compete against the negative aspects of several problems that are inherent to echocardiography. Image quality is subject to the body habitus of patients, and ultrasound imaging in general may yet become a casualty of the obesity epidemic. Over the last decade, a series of tomographic modalities using nuclear medicine, magnetic resonance, and X-ray techniques have been considered as potential replacements for echocardiography. However, the role of echocardiography as the workhorse of cardiovascular imaging is unlikely to change soon—the other modalities are more expensive, less available, and convenient, and several of the modalities involve radiation exposure, the personal and environmental risks of which are increasingly recognized (Table 1). Attention is being directed towards the potential adverse skin and renal side effects of gadolinium use and the exclusion of magnetic resonance in increasing numbers of cardiac patients with implantable devices or ongoing problems.

Although the economics and safety of widespread replacement of echocardiography by other techniques are dubious,

---

**Table 1** Changes that will influence the growth or decline of echocardiography

<table>
<thead>
<tr>
<th>Features favouring the growth of echo</th>
<th>Features favouring the decline of echo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macro-economic perspective—rise of developing economies and ongoing move to cities will lead to overwhelming numbers of people who will need cardiac imaging to guide therapy</td>
<td>Technical difficulty</td>
</tr>
<tr>
<td>Public health perspective—a pandemic of heart failure; ageing populations (especially in western Europe and Japan); obesity, type 2 diabetes, HT, and CAD in the developing world</td>
<td>Increasing prevalence of obesity</td>
</tr>
<tr>
<td>Environmental concerns—radiation, nuclear waste</td>
<td>Erosion of expertise/loss of interest relative to new non-invasive imaging tests</td>
</tr>
<tr>
<td>Health economics</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 7** Use of three-dimensional echo to identify the site and severity of mitral prolapse.
there will certainly be some questions that will be best addressed by these new methods. However, the evolution discussed earlier will position echocardiography as the first choice in imaging, and it will remain pre-eminent in a number of areas. The ability to take the technique to the ‘front line’ of acute care is unparalleled. Although some of the referral indications for transoesophageal echocardiography may be replaced by magnetic resonance, a number of indications (imaging of newborns and babies, transnasal monitoring, assessment during interventions and electrophysiology procedures) will not be replaced by magnetic resonance imaging. The low cost of echocardiography—particularly if the technique can be supported by tele-diagnosis and remote guidance—will make echocardiography the technique of choice in remote locations of the developing and developed worlds. Automation and quantitation will remove some of the skill dependence that limit the current reliability of the method, and this may become critical as cardiologists become more focused on procedural rather than diagnostic work. The next 50 years in echocardiography are likely to be characterized by as much as progress as the last 50 years.

The original echo of classical mythology was a wood-nymph. In punishment for being garrulous, the gods punished her by limiting her power to speak. When the handsome Narcissus saw her, she was unable to communicate with him and he fell in love with her own likeness, the consequences of which were terrible. For cardiac echo to avoid the same fate, it too needs to communicate its ongoing evolution and avoid the label of ‘old technology’.

Supplementary data

Supplementary data are available at European Journal of Echocardiography online.

Funding

Supported in part by grants from the National Health and Medical Research Council, Canberra, Australia.

Conflict of interest: T.M. has obtained research support from GE Healthcare, Philips Medical Systems, siemens and Lanthens for investigations of the new technologies discussed in this paper.

References


