Original Article

Recent advances and future trends in multimodality cardiac imaging

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The cardiovascular imaging field has experienced marked growth and technical advancement in the past several decades. In the future, multimodality imaging will provide enhanced characterisation of disease states. Myocardial perfusion imaging will become more quantitative, permitting measurement of absolute blood flow and coronary flow reserves during stress states. A greater use of positron emission tomography (PET) can be expected for both assessing blood flow quantitatively and molecular imaging of atherosclerotic plaques and myocardial disease states. SPECT and PET imaging of myocardial metabolism and cardiac neuronal imaging have already shown great promise for identifying high-risk patients with coronary heart disease and nonischaemic cardiomyopathy. Further progress will occur in computed tomography imaging of the heart and coronary arteries and cardiac magnetic resonance imaging including quantitative estimates of coronary blood flow, coronary and peripheral vessel plaque characterisation, and detection of myocardial cellular dysfunction. Fusion imaging, in which two disparate image data sets are merged into one functional image, will become commonplace. Major breakthroughs in CV imaging will depend on discoveries in basic research, further refinement of instrumentation and software for image processing and analysis, and outcomes research demonstrating the worth of imaging technologies in reducing cardiovascular death and morbidity.

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Introduction

The field of cardiovascular imaging has experienced marked growth and technological advancement in the past several decades, with new cardiovascular imaging modalities having been introduced in the clinical setting. Multimodality imaging, in which two different types of images of the cardiovascular system are obtained either serially or simultaneously, has permitted better characterisation of myocardial and vascular disease states. Fusion imaging, in which two disparate image datasets are merged into one functional image, is enhancing our capabilities for determining functional consequences of anatomical pathology (e.g., fusion of vessel anatomy from computed tomography coronary angiography with an area of reduced regional blood flow on a myocardial perfusion PET or SPECT scan). We are also witnessing a plethora of "proof of principle" studies in experimental animal models, exploring the worth of new molecular imaging technologies using a variety of imaging devices and molecular probes specific to biologic targets. The most commonly utilised imaging technologies that exist today are cardiac ultrasound, radionuclide imaging, cardiac magnetic resonance (CMR) imaging, and CT imaging. The latter two techniques have successfully been employed to evaluate peripheral vasculature. Invasive imaging modalities exist and are used in the setting of the cardiac catheterisation laboratory. Intravascular ultrasound and optical coherence tomography (OCT) are two such methodologies. Both provide information pertaining to the presence and extent of coronary atherosclerosis, macrophage density or lipid core identification, as well as detecting and quantitating remodelling of atherosclerotic arteries.

This review will discuss and speculate upon the future directions of these imaging modalities. The exception is echocardiography, a mature technology that is constantly being perfected for improved assessment of regional function, valvular pathology, dyssynergy, and perfusion with contrast agents.

It is very difficult to make predictions regarding advances in imaging over the next 5–10 years. So much depends upon breakthroughs in basic research, further refinement of instrumentation and software for image processing and analysis, and the incentives for industry to introduce new imaging applications or novel modalities. The marked increase in volume of conventional imaging tests in the past few years has contributed to the marked rise in health care costs. The imaging tests currently approved and appropriate for clinical use are expensive. The cost has prompted Medicare and other third party payers to be reluctant in approving new car-

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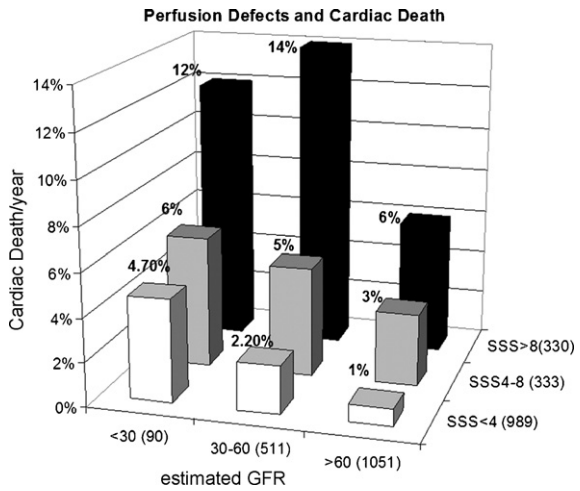

Fig. 1. *Annual cardiac death (CD) rate stratified by severity of perfusion abnormalities expressed as increasing summed stress scores (SSS) and renal function depicted by estimated glomerular filtration rate (eGFR) [3].*

diovascular imaging tests for coverage in their health plans. In the future, new imaging tests must show clinical value in enhancing the quality of care and improving outcomes, while remaining cost-effective, before they will be approved for coverage and payment. Thus, new modalities or new applications of current modalities must be validated in sound clinical research outcomes studies. A controversial example today is coverage for CT coronary angiography. The issue with this anatomic-based technology is whether it is superior and more cost-effective than stress perfusion or stress function tests for physiologically significant CAD. Since this technology currently has a suboptimal positive predictive value – identifying <50% stenoses – it overestimates the severity of CAD and could lead to unnecessary invasive coronary angiographic studies and inappropriate revascularisation.

Future Directions in Myocardial Perfusion Imaging

Today, rest and stress myocardial perfusion imaging (MPI), utilising SPECT or PET radionuclide techniques, are the most commonly performed diagnostic imaging tests to detect CAD and determine risk of future events in patients with suspected or known CAD. The sensitivity, specificity, and normalcy rate for SPECT are 86%, 74%, and 89%, respectively [1]. The prognostic value of normal and abnormal MPI tests has been supported by many studies in the literature. The annual death or nonfatal myocardial infarction rate for patients with a normal stress SPECT scan is 0.8%, whereas the event rate for patients with an abnormal scan is 5.6% annually [2]. The larger and more severe the stress perfusion defects, the worse the outcome. Patients with either Type 2 diabetes or chronic kidney disease have a higher event rate with either a normal or abnormal scan than patients without these comorbidities [2,3] (Fig. 1). Patients with ischaemic scans and depressed LV function have a higher risk of cardiac death than patients with inducible ischaemia and normal LV function [4]. The specificity of SPECT MPI is diminished when attenuation artifacts are interpreted as perfusion abnormalities due to CAD. ECG-gated SPECT improves the specificity as does attenuation-corrected SPECT tomograms [5].

One of the major limitations of stress SPECT imaging for CAD detection is that the extent of CAD is often underestimated [6]. One reason is that the two Tc-99m imaging agents most commonly employed for stress MPI in the clinical setting are sestamibi and tetrofosmin, which show a plateau in myocardial uptake with hyperaemic flows above 2.0 ml/min/g, making it difficult to detect areas of myocardium perfused by mild stenosis [7]. The first-pass myocardial extraction fraction is lower for these perfusion imaging agents than measured for thallium-201 or the PET perfusion tracers [8]. Another limitation of SPECT is that only relative differences in perfusion – from one region of the myocardium to the region with highest myocardial counts – are assessed at rest and during stress, rather than measuring absolute flow changes in ml/min/g. Thus, in some instances of 3-vessel and/or left main CAD, "balanced ischaemia" can occur with stress. This outcome is attributed to diffuse abnormal flow reserve in all areas of the myocardium, which yields homogenous uptake of the tracer when injected during adenosine infusion [6]. Because of this phenomenon, only 25% of patients with 3-vessel disease on angiography have abnormal perfusion or function in the distribution of all three diseased coronary vessels [6]. Similarly, among patients with significant left main CAD, 40% had low risk scans with less than 10% of the LV rendered ischaemic [9]. Some attempts have been made to quantitate coronary flow reserve by dynamic SPECT imaging, which could enhance the accuracy of this technology [10].

Recent advances have been made in SPECT technology, permitting high-speed imaging using a bank of independently controlled detector columns with large-hole tungsten collimators and multiple cadmium zinc telluride crystal arrays [11] (Fig. 2). Using a high-speed camera, the entire stress-rest procedure can be completed within 30 min. The stress and rest data acquisitions take only 4 and 2 min, respectively. Image quality for the high-speed SPECT system is high and myocardial count rates higher than for conventional SPECT cameras. Diagnostic performance of the new system was as good as conventional SPECT with summed stress scores and summed reversibility scores correlating very well ($r = 0.93$) [11]. It is assumed that this new type of digital SPECT systems will replace conventional SPECT cameras over the next five years. Better quantitation for SPECT, including more standardised attenuation and scatter correction algorithms, should emerge and better SPECT-CT systems should be developed for hybrid imaging. Development of three-dimensional (3D) displays and more sophisticated image fusion of disparate imaging technologies (perfusion patterns from SPECT with overlying coronary anatomy from CTA) should accelerate in the next few years. Three-dimensional graphics to overlay results of colour-coded perfusion quantification on a depiction of the left ventricle are already available [12,13]. Such a volumetric represen-