

Non-invasive imaging in cardiology for the generalist

ABSTRACT

In contrast to invasive techniques, the goal of non-invasive cardiac imaging is to identify or exclude heart disease in response to a patient's clinical history of cardiac localizing symptoms. Imaging also aims to establish the risk of an individual developing future heart disease with a view to preventing major cardiovascular events such as myocardial infarction. As well as a role in risk stratification, non-invasive cardiac imaging also helps with decision making for future medical and procedural interventions.

This review outlines the non-invasive imaging modalities available to physicians to identify and risk stratify cardiovascular disease. It discusses the strengths of each imaging technique, in which circumstances it is most useful and its diagnostic accuracy.

Non-invasive cardiac imaging denotes a range of modalities that can be used to determine the structure and function of the heart and its vessels. In contrast to invasive techniques, which involve catheters inserted directly into the heart and vessels, non-invasive imaging relies on illuminating the spectrum of heart diseases with ultrasound, X-rays, scintigraphy and nuclear magnetic resonance.

The goal of non-invasive cardiac imaging is to identify or exclude heart disease in response to a patient's clinical history of cardiac localizing symptoms. Imaging also aims to establish the risk of an individual developing future heart disease with a view to prevent major cardiovascular events such as myocardial infarction. One of the main strengths of non-invasive cardiac imaging is not only risk stratification but also to aid decision making for future medical and procedural interventions. For example a patient presenting with low-risk symptoms of angina may undergo non-invasive computed tomography coronary angiography leading to targeted percutaneous coronary intervention or proceeding directly to coronary artery bypass graft surgery (La Grutta et al, 2017).

Dr Mark J Davies, Cardiology Registrar, Division of Cardiovascular Medicine, Radcliffe Department of Medicine, University of Oxford, Oxford, and Department of Cardiology, Wycombe Hospital, Buckinghamshire NHS Trust, High Wycombe, Buckinghamshire HP11 2TT

Dr James D Newton, Consultant Cardiologist, Oxford Heart Centre, Oxford University Hospitals NHS Foundation Trust, John Radcliffe Hospital, Oxford

Correspondence to: Dr MJ Davies
(mark.davies@cardiov.ox.ac.uk)

This review outlines the non-invasive imaging modalities available to physicians to discern cardiovascular disease. It discusses the strengths of each imaging technique, in which circumstances it is most useful and the diagnostic accuracy of each modality.

Echocardiography

Transthoracic echocardiography

Transthoracic echocardiography is the primary non-invasive imaging modality for quantitative and qualitative evaluation of cardiac anatomy and function. Two-dimensional echocardiography provides tomographic or 'thin slice' imaging of the dimensions, volumes, and systolic and diastolic function of the heart and, via Doppler, an assessment of the direction and velocities of blood flow through the heart (Evangelista et al, 2008). Comprehensive echocardiographic examination typically involves imaging the heart from multiple orientations with each tomographic view defined by the transducer position (parasternal, apical, subcostal, suprasternal) and view (long axis, short axis, four-chamber, five-chamber) (*Figure 1*). These two-dimensional 'slices' are then interpreted by the operator to determine the anatomy and function as a whole. Transthoracic echocardiography can provide accurate blood flow velocities through different chambers of the heart. Using these Doppler techniques allows the operator to determine the speed, timing and direction with accuracy. Pressure can be then inferred using the simplified Bernoulli equation:

$$\text{Pressure (mmHg)} = 4V^2 \text{ [where } V = \text{peak velocity m/s]}$$

The pressure gradient can be inferred from the pressure difference from two chambers at a single time point. It is important to note that echocardiography can only infer the pressure difference between two chambers and does not reflect the actual pressure in the chamber. Transthoracic echocardiography can also estimate the cross-sectional area of an orifice such as a stentic valve by using the continuity equation, where the flow volume in one position should be equal to another as long as there are no shunts between the two areas. These two echocardiographic parameters are used to determine the pressure gradients and valve areas and are a useful non-invasive method to monitor valvular heart disease (e.g. aortic stenosis).

Ultrasound platforms equipped with three-dimensional technology have been developed to enhance the interpretation and display of the anatomy and function

Figure 1. Transthoracic echocardiogram demonstrating apical four-chamber view.



– generally by acquiring a volumetric data set, which can then be displayed in custom orientations (Cai and Ahmad, 2012). The specific clinical advantages of three-dimensional echocardiography are still being refined and becoming increasingly clinical important.

Transoesophageal echocardiography

While technically an invasive procedure as an instrument is passed into the body, transoesophageal echocardiography is included here as the risk of the procedure is minimal and does not involve accessing the heart or blood vessels directly. Transoesophageal echocardiography provides superior image quality, particularly for posterior cardiac structures that are nearer to the oesophagus which are often less well visualized using transthoracic echocardiography (Wamil et al, 2017). Transthoracic echocardiography remains the initial test of choice for most patients requiring an echocardiogram, although transoesophageal echocardiography should be performed as the initial test in certain life-threatening situations or in situations where transthoracic echocardiography is likely to be non-diagnostic (Flachskampf et al, 2014). These include acute aortic pathology (i.e. dissection, transection, intramural haematoma), prosthetic valve dysfunction, complications of endocarditis (e.g. fistulae, abscess), evaluation of the left atria or left atrial appendage for thrombus in a patient with atrial fibrillation or atrial flutter to facilitate clinical decision making regarding anticoagulation, cardioversion or ablation, and evaluation of source of embolism in a young patient with normal transthoracic echocardiography (Omran et al, 1999).

Stress echocardiography

Echocardiography enables evaluation of cardiac function at rest, during pharmacological stress, and during or immediately following dynamic exercise. Exercise two-dimensional imaging is used primarily to detect the presence and extent of coronary artery disease by provoking transient regional ischaemia with resulting wall motion abnormalities (Rösner et al, 2017). The addition of exercise Doppler permits evaluation of valvular function, pulmonary artery pressure, left ventricular outflow tract gradients, and global ventricular systolic and diastolic function.

Figure 2. Computed tomography coronary angiogram demonstrating unobstructed left circumflex coronary artery (Cx) and posterior descending artery (PDA).



Stress echocardiography can be accomplished using either exercise (treadmill or bicycle) or pharmacological agents (predominantly dobutamine) as the stress mechanism. Echocardiographic contrast agents may be useful in enhancing endocardial border definition when two or more segments of the left ventricle are not well visualized. Based on data in patients with suspected coronary artery disease, stress echocardiography has demonstrated very good diagnostic accuracy for detecting or excluding significant coronary artery disease, with a mean sensitivity of 81%, a specificity of 86% and overall accuracy of 84% (Mattoso et al, 2017).

Cardiac computed tomography

A traditional computed tomography scan is an X-ray procedure that combines sequential thin slice X-ray generated by rotating the X-ray source around the body into cross-sectional views at standard tomographical plains. Cardiac computed tomography uses advanced computed tomography technology with intravenous contrast (radio-opaque dyes) to visualize the cardiac anatomy, coronary circulation and great vessels (Figure 2). There are two broad types of cardiac computed tomography which are in clinical practice – computed tomography calcium scoring and computed tomography coronary angiography (Williams et al, 2017).

Computed tomography calcium score

In the 1980s Dr Arthur Agatston defined a method to assess the amount of coronary artery calcium by using electron beam computed tomography, otherwise known as ultrafast computed tomography scan. The density of calcium is measured in Hounsfield units and when

66 In addition to the quantification of calcium, a new generation of multislice computed tomography scanners permits the non-invasive acquisition of very high-quality coronary computed tomography angiography. 99

multiplied by the area of the coronary calcification provides the calcium score, commonly termed the Agatston score (Blaha et al, 2017).

The amount of calcium in the wall of the coronary arteries, assessed by the Agatston score, appears to be a better predictor of risk than standard risk factors. The presence and extent of coronary calcium are markers of the extent of atherosclerosis within the coronary arteries. Nonetheless, it is important to understand that the coronary calcium score does not necessarily reflect the severity of narrowing (the degree of stenosis). Still, a patient with a high calcium score is more likely to have a significant narrowing of a coronary artery than a patient with a low calcium score (Hegde and Rajendran, 2016).

The whole-heart Agatston score has been shown to be independent of traditional risk factors; however, the overall predictive accuracy is relatively modest as it does not take into consideration the spatial distribution and regional characteristics of individual calcified lesions. Furthermore, because it lacks spatial distribution information it cannot distinguish between plaque located in high risk areas *vs* low risk areas. This led to the development of a lesion-specific calcium score (Hegde and Rajendran, 2016). This is where each individual calcified lesion is characterized and precisely measured using parameters including but not limited to the width, length, density and distance from the entrance of the major coronary arteries. This lesion-specific calcium scoring method is superior to the traditional Agatston score for the prediction of significant epicardial coronary stenoses.

Computed tomography coronary angiography

In addition to the quantification of calcium, a new generation of multislice computed tomography scanners permits the non-invasive acquisition of very high-quality coronary computed tomography angiography. When compared with invasive coronary angiography, multidetector computed tomography has a high discriminative power to detect significant obstructive coronary artery disease, with a sensitivity and specificity in the 90% range (Leipsic and Blanke, 2017). Multidetector computed tomography does have limitations, including higher radiation exposure, the need to administer contrast media, and the need to obtain a heart rate of 65 beats per minute or less. Patients receive intravenous beta-blockers to achieve a slow resting heart rate to increase diastole, reduce motion artifact and enable optimal imaging acquisition during mid-diastolic coronary artery blood flow. Computed tomography

coronary angiography has been limited to sinus rhythm as patients with common arrhythmia such as atrial fibrillation have irregular motion artifacts providing non-diagnostic imaging. However, modulation of electrocardiogram gating and speed of image acquisition through rapid multidetectors has allowed successful imaging of these patient subgroups.

With the advent of subsecond gantry rotation combined with multislice computed tomography, high resolution and high speed can be obtained at the same time, allowing excellent imaging of the coronary arteries. Images with an even higher temporal resolution can be formed using retrospective electrocardiogram gating (Matsubara et al, 2016). In this technique, each portion of the heart is imaged more than once while an electrocardiogram trace is recorded. The electrocardiogram is then used to correlate the computed tomography data with the corresponding phases of cardiac contraction. Once this correlation is complete, all data that were recorded while the heart was in motion (systole) can be ignored and images can be made from the remaining data that happened to be acquired while the heart was at rest (diastole). In this way, individual frames in a cardiac computed tomography investigation have a better temporal resolution than the shortest tube rotation time. Computed tomography coronary angiography has a diagnostic sensitivity for the detection of stenosis of more than 75% and a specificity of 97% (Lee et al, 2012), providing an excellent rule-out test for patients who are at low risk for suspected coronary artery disease.

Nuclear cardiology

Radionuclide myocardial perfusion imaging enables evaluation of cardiac perfusion and function at rest and during dynamic exercise or pharmacological stress for the diagnosis and management of patients with known or suspected coronary heart disease (Rubeaux et al, 2016). Radionuclide myocardial perfusion imaging requires the administration of a radioactive perfusion tracer (also called a radiopharmaceutical or radioisotope), usually intravenously, and a special camera system – single-photon emission computed tomography or positron emission tomography – to detect the gamma photons (*Figure 3*). Myocardial perfusion images are usually acquired at rest and following stress, with increasing adoption of stress-only imaging, and many available combinations of one- *vs* two-day rest-first *vs* stress-first protocols. A specialized computer program reconstructs the acquired images into standard displays.

Myocardial perfusion imaging provides important information on rest and post-stress myocardial perfusion, viability, and global and regional left ventricular systolic function, which generally signify the presence and extent of underlying coronary artery disease. In addition, myocardial perfusion imaging is a powerful tool for risk stratification of patients with known or suspected coronary artery disease, particularly if patients have had previous

myocardial infarcts. It allows physicians to determine the difference between reversible myocardial ischaemia and completed myocardial infarcts comprising non-viable heart muscle. Myocardial perfusion imaging has a diagnostic sensitivity for the detection of ischaemic heart disease of 95% and a specificity of 83% (Elhendy, 2016; Poulin et al, 2016).

Cardiac magnetic resonance imaging

Cardiac magnetic resonance imaging proves useful for evaluating right and left ventricular function, cardiac masses and congenital heart disease, and for identifying patients with suspected arrhythmogenic right ventricular cardiomyopathy. Cardiac magnetic resonance imaging characterizes the tissue with greater accuracy than other imaging techniques (Delgado et al, 2016). It also allows accurate assessment of three-dimensional volume and function, which is of particular interest for the right ventricle because of its complex crescent shape compared to the ellipsoidal shape of the left ventricle (*Figure 4*).

Cardiac magnetic resonance imaging angiography is a standard technique for imaging the aorta and large vessels of the chest and abdomen, as well as assessing the origin and course of the coronary arteries. Cardiac magnetic resonance imaging evaluates the presence of coronary artery disease by multiple techniques including:

- Direct visualization of coronary stenoses
- Determination of flow within the coronary arteries
- Evaluation of myocardial perfusion and metabolism
- Assessment of abnormal wall motion during stress
- Identification of infarcted myocardium as well as viable myocardium using delayed hyperenhancement imaging with gadolinium contrast.

The diagnostic accuracy of cardiac magnetic resonance imaging has a sensitivity 89% and specificity of 92% for the detection of viable myocardium in patients with ischaemic heart disease (Puntmann et al, 2016a,b).

New techniques with cardiac magnetic resonance imaging perfusion imaging have demonstrated the ability to detect high-grade coronary artery stenoses and to characterize the severity of valvular disease. Its improved spatial resolution and diagnostic accuracy is leading to wider use as a non-invasive imaging modality (Blankstein and Shah, 2016; Rogers and Waksman, 2016).

Future advances

Non-invasive cardiac imaging has flourished over the last few decades as a result of faster and more accurate technology, with each core modality evolving to offer additional diagnostic and functional information (*Table 1*).

In cardiac computed tomography, technical development is oriented toward creating machines with multiple detectors that will reduce both acquisition time and the amount of ionizing radiation delivered, as well as optimizing tissue characterization by using dual-energy systems or spectral energy (Lee et al, 2016).

Figure 3. Technetium (^{99m}Tc) tetrofosmin myocardial perfusion scan.

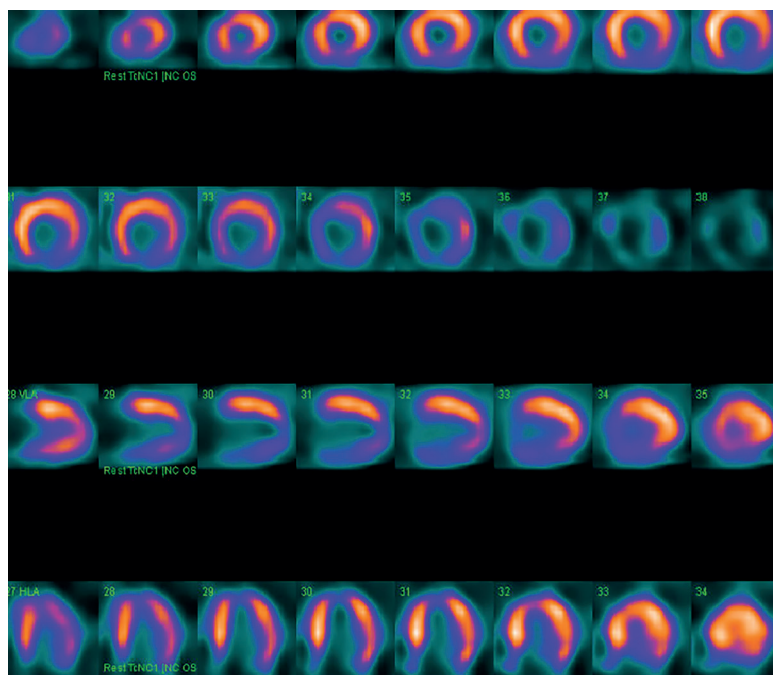
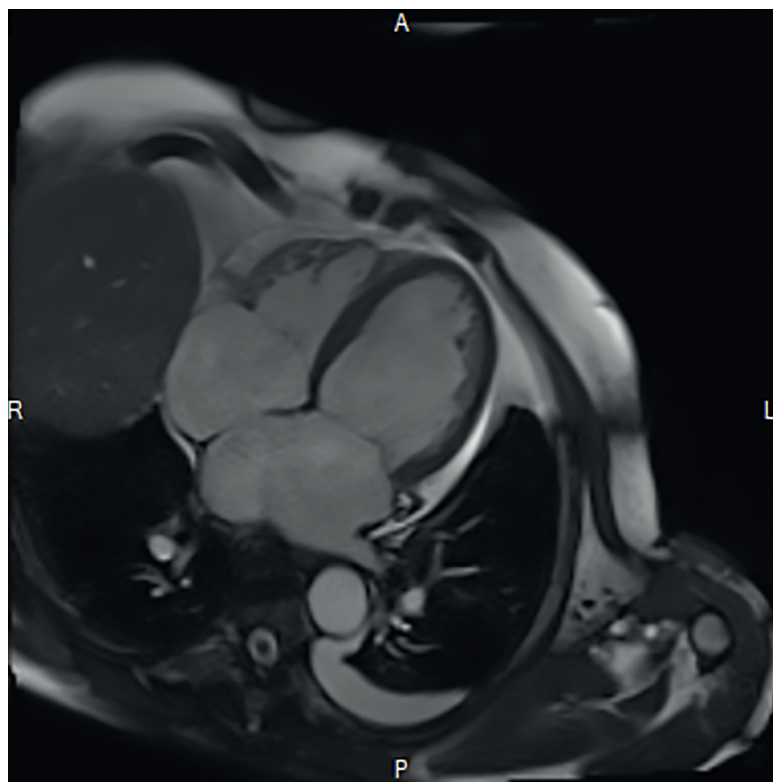


Figure 4. Cardiac magnetic resonance image demonstrating four-chamber view.



In the field of cardiac magnetic resonance imaging, two novel approaches stand out, both of which are promising. One is diffusion magnetic resonance imaging, which provides three-dimensional visualization of the myocardial and cardiac myofibrillar architecture through the diffusion of water molecules and could advance our understanding of cardiac contractility and remodeling processes, as well as post-infarction healing (Mekkaoui et al, 2016). The

Table 1. Comparison of the strengths and limitations of non-invasive cardiac imaging

	Ultrasound	Cardiac computed tomography	Nuclear cardiology	Cardiac magnetic resonance	Hybrid
Example image	<i>Figure 1</i>	<i>Figure 2</i>	<i>Figure 3</i>	<i>Figure 4</i>	
Availability	+++	++	+	++	+/-
Cost	£	££	££	£££	£££
Risks	None	☼ Contrast agent	☼☼	Non-ionizing* Contrast agent	☼☼☼
Structural assessment	Able to assess chambers, valves and great vessels. Limited by patient factors (e.g. comorbidities, adequate windows)	Good spatial resolution of cardiac anatomy including coronary arteries	Good spatial resolution of cardiac anatomy. Infer coronary artery territories but not anatomy	Excellent spatial resolution of cardiac anatomy, coronary arteries and great vessel. Particularly good at right ventricle complex anatomy	Good spatial resolution of cardiac anatomy including coronary arteries
Functional assessment	Dynamic assessment of chambers and valvular systolic and diastolic function. Valve measurements inferred by continuity equation	Usually static images with no assessment of function	Accurately determine left ventricle volume and function	Excellent functional assessment of chambers and valves. Accurate systolic and diastolic function	Accurately determine left ventricle volume and function
Blood flow	Doppler measurements of blood flow between chambers. Pressure gradients inferred by Bernoulli equations	Characterization of blood flow through coronary arteries. Using fluid dynamic modelling, computed tomography – fractional flow reserve identifying functional anatomical stenosis	Does not identify blood flow directly, infers discrepancy with perfusion changes	Excellent assessment of blood flow through chambers, coronary arteries and within the myocardium	Does not identify blood flow directly, infers discrepancy with perfusion changes
Ischaemia detection	Stress echocardiography can identify inducible regional wall abnormalities	Unable to detect ischaemia	Able to determine ischaemic burden with perfusion tracer uptake at rest and during exercise	Able to determine using perfusion imaging hyperaemia, indicating ischaemic myocardium	Able to correlate coronary artery stenosis with perfusion tracer uptake at rest and during exercise to identify significant lesions
Infarction detection	Thin, akinetic regional wall abnormalities at rest indicate prior infarction	Unable to detect infarction	Able to detect perfusion uptake mismatch to determine infarction	Late gadolinium enhancement highlights areas of myocardial infarct. Can even distinguish acute necrosis from fibrotic scar in infarcted myocardium	Able to correlate coronary artery stenosis with perfusion tracer uptake to identify significant lesions
Viability assessment	Hypokinetic areas indicate strain which may be viable at rest. No inducible assessment of viability	Unable to determine viability	Able to quantify the burden of ischaemia and viability though perfusion tracer uptake	Accurate determination of myocardial viability based on perfusion characteristics	Able to correlate the stenosis with the burden of ischaemia and viability though perfusion tracer uptake
Metabolic function	Poor assessment, global appreciation of dysfunction	Unable to determine metabolic function	Tracer specificity can characterize cardiac metabolic function	Cardiac magnetic resonance spectroscopy accurately measures the abundance of metabolites within the myocardium in vivo, gaining insight into the cardiac metabolic changes in differing states	Tracer specificity can characterize cardiac metabolic function. Molecular tracers can identify hot atheroma along coronary arteries

*Theoretical risk to fetus during first trimester but is generally safe. Gadolinium contrast is avoided in pregnancy.

other technique currently being developed is magnetic resonance imaging spectroscopy, which provides high-sensitivity information on cardiac metabolic processes using molecules such as carbon, sodium, phosphorous and fluorine (Pumphrey et al, 2016). The possibility of using a 3T electromagnetic field could accelerate the use of spectroscopy to evaluate cardiovascular disease.

One example that demonstrates the unity of non-invasive imaging with target ligand tracers is characterizing cardiac amyloidosis. Work demonstrating targeted amyloid-imaging agent (i.e. ^{11}C -Pittsburg compound, ^{18}F Florbetapir) binding to amyloid fibrils within the myocardium raising the possibilities of using these imaging tools for early detection of cardiac involvement (Bokhari et al, 2014). This research has also highlighted the possibility of using established ligands ($^{99\text{m}}\text{Tc}$ -based tracers such as $^{99\text{m}}\text{Tc}$ -PYP or $^{99\text{m}}\text{Tc}$ -DPD) that normally bind to bone, which have been shown to highlight transthyretin fibrils in these amyloid hearts (Ruberg and Miller, 2013).

However, this decade's biggest revolution in cardiovascular imaging and innovation is the development of hybrid technology using multimodality imaging (e.g. computed tomography coronary angiography and positron emission tomography) to accurately understand the disease process underlying the clinical presentation (Rischpler and Nekolla, 2016). Cardiac computed tomography-positron emission tomography systems have the ability to combine vessel anatomy from computed tomography coronary angiography with an area of reduced regional blood flow on a myocardial perfusion positron emission tomography or single-photon emission computed tomography scan. This combined anatomical and functional imaging is superior to computed tomography coronary angiography alone in predicting significant coronary artery disease although at the cost of slightly increased radiation. Furthermore, they permit revascularization decisions to be made from a single imaging test without the need for a second invasive or non-invasive test.

The exponential growth of technology is enabling a quantum leap in the development of new imaging equipment and the establishment of new clinical applications. These advances include the optimization of spatial and temporal resolution for each of the techniques, using lower amounts of radiation and improving safety. As technology for cardiovascular imaging improves, so must the diagnostic accuracy and correlation with the clinical understanding of each disease. If one detects disease progression at an ever-earlier stage, does this justify treatment recommendations before clinical symptoms? One may predict the need for clinical trials to answer which imaging modality best answers the respective clinical question. **BJHM**

Conflict of interest: none.

Blaha MJ, Whelton SP, Al Rifai M et al (2017) Rationale and design of the coronary artery calcium consortium: A multicenter cohort study. *J Cardiovasc Comput Tomogr* **11**(1): 54–61. <https://doi.org/10.1016/j.jcct.2016.11.004>

Blankstein R, Shah RV (2016) CMR to evaluate bioprosthetic aortic

KEY POINTS

- Non-invasive cardiac imaging uses a range of modalities that can be used to determine the structure and function of the heart and its vessels.
- Non-invasive cardiac imaging aims to identify or exclude heart disease in response to a patient's clinical history of cardiac localizing symptoms.
- The main strength of non-invasive cardiac imaging is to determine cardiac disease and aid decision making for future medical and procedural interventions while mitigating any invasive risk to patients.
- Non-invasive cardiac imaging is experiencing exponential growth in technology and is enabling a quantum leap in the establishment of new clinical applications.

stenosis? *JACC Cardiovasc Imaging* **9**(7): 794–796. <https://doi.org/10.1016/j.jcmg.2015.11.026>

- Bokhari S, Shahzad R, Castaño A, Maurer MS (2014) Nuclear imaging modalities for cardiac amyloidosis. *J Nucl Cardiol* **21**(1): 175–184. <https://doi.org/10.1007/s12350-013-9803-2>
- Cai Q, Ahmad M (2012) Three-dimensional echocardiography in valvular heart disease. *Echocardiography* **29**(1): 88–97. <https://doi.org/10.1111/j.1540-8175.2011.01523.x>
- Delgado V, Bucciarelli-Ducci C, Bax JJ (2016) Diagnostic and prognostic roles of echocardiography and cardiac magnetic resonance. *J Nucl Cardiol* **23**(6): 1399–1410. <https://doi.org/10.1007/s12350-016-0595-z>
- Elhendy A (2016) Prognostic significance of ischemia location on stress myocardial perfusion SPECT: tracing the fingerprints of the widow maker. *J Nucl Cardiol* **23**(2): 285–286. <https://doi.org/10.1007/s12350-015-0121-8>
- Evangelista A, Flachskampf F, Lancellotti P et al; European Association of Echocardiography (2008) European Association of Echocardiography recommendations for standardization of performance, digital storage and reporting of echocardiographic studies. *Eur J Echocardiogr* **9**(4): 438–448. <https://doi.org/10.1093/ejchocard/jen174>
- Flachskampf FA, Wouters PE, Edvardsen T et al (2014) Recommendations for transoesophageal echocardiography: EACVI update 2014. *Eur Heart J Cardiovasc Imaging* **15**(4): 353–365. <https://doi.org/10.1093/ehjci/jeu015>
- Hegde M, Rajendran R (2016) SYNTAX score in patients with high computed tomography coronary calcium score. *J Clin Imaging Sci* **6**(1): 46. <https://doi.org/10.4103/2156-7514.193423>
- La Grutta L, Marasà M, Toia P et al (2017) Integrated non-invasive approach to atherosclerosis with cardiac CT and carotid ultrasound in patients with suspected coronary artery disease. *Radiol Med (Torino)* **122**(1): 16–21. <https://doi.org/10.1007/s11547-016-0692-8>
- Lee YW, Yang CC, Mok GSP, Law WY, Su CT, Wu TH (2012) Prospectively versus retrospectively ECG-gated 256-slice CT angiography to assess coronary artery bypass grafts comparison of image quality and radiation dose. *PLoS ONE* **7**(11): e49212. <https://doi.org/10.1371/journal.pone.0049212>
- Lee HJ, Im DJ, Youn JC et al (2016) Myocardial extracellular volume fraction with dual-energy equilibrium contrast-enhanced cardiac CT in nonischemic cardiomyopathy: a prospective comparison with cardiac MR imaging. *Radiology* **280**(1): 49–57. <https://doi.org/10.1148/radiol.2016151289>
- Leipsic J, Blanke P (2017) Prognostic value of coronary CT angiography: lessons from the West Denmark Cardiac Registry. *Eur Heart J* **38**(6): 422–424. <https://doi.org/10.1093/eurheartj/ehw634>
- Matsubara K, Sakuda K, Nunome H, Takata T, Koshida K, Gabata T (2016) 128-slice dual-source CT coronary angiography with prospectively electrocardiography-triggered high-pitch spiral mode: radiation dose, image quality, and diagnostic acceptability. *Acta Radiol* **57**(1): 25–32. <https://doi.org/10.1177/0284185114562467>
- Mattoso AAA, Tsutsui JM, Kowatsch I et al (2017) Prognostic value of dobutamine stress myocardial perfusion echocardiography in patients with known or suspected coronary artery disease and normal left ventricular function. *PLoS ONE* **12**(2): e0172280. <https://doi.org/10.1371/journal.pone.0172280>
- McKkaoui I, Moulin K, Croisille P, Pousin J, Viallon M (2016)

- Quantifying the effect of tissue deformation on diffusion-weighted MRI: a mathematical model and an efficient simulation framework applied to cardiac diffusion imaging. *Phys Med Biol* **61**(15): 5662–5686. <https://doi.org/10.1088/0031-9155/61/15/5662>
- Omran H, Jung W, Rabahieh R et al (1999) Imaging of thrombi and assessment of left atrial appendage function: a prospective study comparing transthoracic and transoesophageal echocardiography. *Heart* **81**(2): 192–198. <https://doi.org/10.1136/hrt.81.2.192>
- Poulin MF, Alexander S, Doukky R (2016) Prognostic implications of stress modality on mortality risk and cause of death in patients undergoing office-based SPECT myocardial perfusion imaging. *J Nucl Cardiol* **23**(2): 202–211. <https://doi.org/10.1007/s12350-014-0064-5>
- Pumphrey A, Yang Z, Ye S et al (2016) Advanced cardiac chemical exchange saturation transfer (cardioCEST) MRI for *in vivo* cell tracking and metabolic imaging. *NMR Biomed* **29**(1): 74–83. <https://doi.org/10.1002/nbm.3451>
- Puntmann VO, Carr-White G, Jabbour A et al; International T1 Multicentre CMR Outcome Study (2016a) T1-mapping and outcome in nonischemic cardiomyopathy. *JACC Cardiovasc Imaging* **9**(1): 40–50. <https://doi.org/10.1016/j.jcmg.2015.12.001>
- Puntmann VO, Peker E, Chandrasekhar Y, Nagel E (2016b) T1 mapping in characterizing myocardial disease. *Circ Res* **119**(2): 277–299. <https://doi.org/10.1161/CIRCRESAHA.116.307974>
- Rischpler C, Nekolla SG (2016) PET/MR imaging in heart disease. *PET Clin* **11**(4): 465–477. <https://doi.org/10.1016/j.cpet.2016.05.006>
- Rogers T, Waksman R (2016) Role of CMR in TAVR. *JACC Cardiovasc Imaging* **9**(5): 593–602. <https://doi.org/10.1016/j.jcmg.2016.01.011>
- Rösner A, Schirmer H, Iqbal A, Bijns B, Avenarius D, Malm S (2017) Assessment of myocardial ischemia by strain dobutamine stress echocardiography and cardiac magnetic resonance perfusion imaging before and after coronary artery bypass grafting. *Echocardiography* **34**(4): 557–566. <https://doi.org/10.1111/echo.13471>
- Rubeaux M, Xu Y, Germano G, Berman DS, Slomka PJ (2016) Normal databases for the relative quantification of myocardial perfusion. *Curr Cardiovasc Imaging Rep* **9**. pii: 22. <https://doi.org/10.1007/s12410-016-9385-x>
- Ruberg FL, Miller EJ (2013) Nuclear tracers for transthyretin cardiac amyloidosis: time to bone up? *Circ Cardiovasc Imaging* **6**(2): 162–164. <https://doi.org/10.1161/CIRCIMAGING.113.000178>
- Wamil M, Bull S, Newton J (2017) The modern role of transoesophageal echocardiography in the assessment of valvular pathologies. *Echo Res Pract* **4**(1): R1–R13 <https://doi.org/10.1530/ERP-16-0034>
- Williams MC, Hunter A, Shah A et al; Scottish Computed Tomography of the HEART (SCOT-HEART) Trial Investigators (2017) Symptoms and quality of life in patients with suspected angina undergoing CT coronary angiography: a randomised controlled trial. *Heart* <https://doi.org/10.1136/heartjnl-2016-310129>

Organised by

BRITISH JOURNAL OF
**HOSPITAL
MEDICINE**

In association with



Assessment and Management of Lipoedema

A practical overview for physicians, surgeons and specialist nurses

The Hatton, London
Thursday 19th October 2017

Benefits of attending:

- Improve understanding of the current best practice guidelines
- Learn about the challenges of assessing lipoedema
- Hear about the different treatment options available
- Discuss how we can improve services in the future
- Share and exchange ideas with the leading experts in the field

To book your place:  Call us on +44(0)20 7501 6768

 www.mahealthcarevents.co.uk/lipoedema2017

