CHAPTER 14

Medical Imaging of the Heart and Cardiovascular System

Zhonghua Sun¹, Kwan-Hoong Ng², Patrick C. Brennan³

¹Discipline of Medical Imaging, Department of Imaging and Applied Physics, Curtin University, Perth 6845, Australia
²Department of Biomedical Imaging, University of Malaya, Kuala Lumpur 50603, Malaysia
³Department of Medical Imaging and Radiation Sciences, University of Sydney, Sydney 2141, Australia

CONTENTS

1. Introduction .................................... 214
2. Imaging Principles .................................. 214
3. Invasive Imaging Modalities ........................ 215
   3.1. Invasive Cardiac Angiography ................. 215
   3.2. Intravascular Ultrasound ...................... 215
4. Less Invasive Imaging Modalities .................... 217
   4.1. Chest Radiography .......................... 217
   4.2. Electron Beam Computed Tomography ........... 217
   4.3. Computed Tomography ...................... 219
   4.4. Magnetic Resonance Imaging .................. 222
   4.5. Doppler Ultrasonography ..................... 224
   4.6. Echocardiography ........................... 226
5. Nuclear Medicine Imaging Modalities .................. 226
   5.1. Single Photon Emission Computed Tomography ... 227
   5.2. Positron Emission Tomography ................. 228
   5.3. Hybrid Imaging Modalities .................... 229
6. Ionizing Radiation Examinations-Radiation Dose Issue ........ 230
   6.1. Radiation Doses Relevant to Cardiac Angiography and Associated Interventional Procedures .......... 231
1. INTRODUCTION

Numerous diagnostic imaging studies are performed to visualize the vasculature of the heart and cardiovascular system that transports blood to and from the heart. The circulatory system is responsible for moving the blood throughout the body so as to carry oxygen and nutrients to the various tissues in the peripheral body and remove any waste products for elimination. As in any closed system, problems can occur that compromise the normal function of the circulatory system supplying the heart and cardiovascular system. Common situations that cause malfunction of the system are reduced or increased blood flow, and directional anomalies that can cause flow in the wrong direction between different cardiac chambers. The purpose of diagnostic and interventional imaging procedures is to identify and manage these problems.

In most industrialized countries cardiovascular disease is still the leading cause of morbidity and mortality [1]. The most threatening manifestations of cardiovascular disease are carotid artery stenosis, coronary artery disease, renal artery stenosis, peripheral artery stenosis, or occlusion with potentially fatal consequences of stroke, myocardial infarction, hypertension or limb loss, respectively [2–4]. Since cardiovascular disease is not only life-threatening but also presents a major economic burden to the health care system, early detection and a comprehensive assessment of detected atherosclerotic changes or disease screening are very important to improve treatment outcome and patient management. Medical imaging plays an important role in the early detection and diagnosis of cardiovascular disease. Imaging of the heart and cardiovascular system has undergone rapid developments over the last decade due to advancement in medical imaging techniques, such as multislice computed tomography (MSCT), magnetic resonance imaging (MRI), and nuclear medicine imaging, especially hybrid functional and anatomic imaging techniques, such as positron emission tomography and computed tomography (PET/CT). The following sections in this chapter will discuss imaging principles, followed by a description of each imaging modality used in cardiac imaging with reference to the advantages and disadvantages.

2. IMAGING PRINCIPLES

Imaging of the heart and cardiovascular system is different from that of other parts of the body, since the heart is a fast-moving organ and peripheral vessel branches are small in diameter. This puts a strong demand on the technical aspects of imaging modalities. In order to acquire high-resolution artifact-free images of the heart and cardiovascular system, two technical aspects are essential to accomplish this goal, namely, high temporal and spatial resolution. This translates into fast image acquisition times and multiple data acquisition at submillimeter slice thickness. High temporal resolution is particularly important for heart imaging as it relates to the speed of data acquisition, which is needed to image the beating heart without motion artifacts. Multiple data acquisition with high spatial resolution refers to the need to cover the heart and cardiovascular system in its entirety within a single breath-hold. This is necessary to visualize and demonstrate the tiny artery branches such as the coronary artery and its branches, since the coronary artery tree has a small diameter of 1.5–3 mm.

Traditionally, imaging of the heart and cardiovascular system is performed with invasive catheter-based angiography, which is still regarded as the gold standard technique. However, it is not only an invasive procedure, but also associated with procedure-related complications [5]. Less invasive modalities have developed rapidly, such as MSCT and
MRI, achieving improved diagnostic value in cardiovascular imaging when compared to invasive angiography [6–8]. Furthermore, physiological evaluation modalities including single photon emission computed tomography (SPECT) and PET, have also been increasingly used in cardiac imaging due to their unique ability to provide functional assessment of the heart and cardiovascular disease [9, 10].

3. INVASIVE IMAGING MODALITIES

Invasive imaging modalities include catheter-based invasive angiography, which is regarded as the gold standard method, and intravascular ultrasound, which is useful for assessing both normal appearance and abnormal changes of blood vessels in the presence of pathologies, such as plaque formation in the artery wall. Despite invasiveness and presence of procedure-related complications, these modalities still continue to play an important role in the diagnosis and assessment of cardiovascular disease.

3.1. Invasive Cardiac Angiography

Invasive angiography is a radiographic technique used to diagnose vascular disease of the main artery, aorta, and its distal branches such as those supplying the lower extremities. It is performed by introducing the catheter into the aorta via vascular access. The most common vascular access for catheter insertion to perform all angiography procedures is the percutaneous route. The transfemoral artery approach is the most common one for aortography, which is normally performed to image the aorta and its artery branches. Transaxial puncture is alternatively selected when pathology, such as atherosclerosis or aortofemoral grafts, make the transfemoral approach undesirable. If the aim of the procedure is to assess the right heart or pulmonary circulation, the transfemoral venous route is desirable.

Selective studies, such as left and right heart catheterisation and coronary angiography, can be performed following aortography depending on patient history, clinical diagnosis, and electrocardiography anomalies. One of the most common selective procedures is coronary angiography. It is performed to image the coronary, its branches, and collateral circulations for diagnosis of coronary artery disease, as well as treatment planning.

Cardiac angiography is the method of choice for cardiac imaging owing to its high spatial and temporal resolution, which is still unsurpassed by other imaging modalities. It is performed on patients with coronary artery disease, conduction disturbances, or congenital heart disease and provides excellent information regarding heart and vessel anatomy (Fig. 1). Cardiac angiography also allows for intracardiac and arterial pressure measurements as the catheter passes through the various areas of the heart. This helps the cardiologist make an accurate diagnosis of the pathology in order to determine the cardiac function and proper intervention procedures.

Cardiac angiography is also increasingly used to perform therapeutic angiography through expanded use of interventional procedures. Percutaneous transluminal coronary angioplasty (PTCA) is a therapeutic procedure commonly performed to dilate stenosed or occluded coronary arteries with a balloon catheter, followed by placement of stents in the vessel with the aim of maintaining the patency of narrowed vessels. Thrombolysis is a procedure in which an anticoagulant drug is administered onto a clot to dissolve it. With embolization, devices, such as coils, are used to clot off vessels, for instance, vessels feeding tumors (to shrink the tumor and reduce peri-operative bleeding), arteriovenous malformations, occlude fistulae, or other abnormalities to prevent excessive bleeding during open surgery.

3.2. Intravascular Ultrasound

Invasive cardiac angiography, as the gold standard technique for evaluating cardiovascular disease, provides excellent information on lumen size and pathological changes such as degree of vessel stenosis; however, it is limited to assessment of vascular remodelling and is not used for the evaluation of wall thickness or plaque composition. Instead,
intravascular ultrasound (IVUS) is considered a more accurate method for visualizing the artery wall, especially the coronary artery and intraluminal plaque composition and volume [11].

IVUS is performed as part of the invasive diagnostic procedure. Following cardiac angiography, the IVUS catheter is introduced after the patient has been given an intravascular administration of nitroglycerin. The ultrasound catheter tip position is determined by fluoroscopy angiography through infusion of contrast medium, and the catheter is positioned distal to the lesion of interest. During pullback, gray scale IVUS data is stored digitally and assessed offline by the IVUS software system [12].

IVUS is a recently developed imaging technique that generates high-quality tomographic images of cardiovascular disease, such as coronary atheroma [13]. Using a motorized pullback apparatus, a series of cross-sectional measurements can be obtained and summed to determine plaque composition, plaque volume, or atheroma burden. Several characteristics inherent to IVUS imaging offer potential advantages in the evaluation of cardiovascular disease. This tomographic orientation allows for visualization of the full circumference of the vessel wall, examination of arterial remodelling, and assessment of the thickness and echogenicity of atherosclerotic plaques [14, 15]. Gray scale IVUS is a useful modality for characterizing the extent and distribution of atherosclerotic plaques in vivo, as well as for determining the morphology of atherosclerotic plaques and the vessel wall [16, 17] (Fig. 2). It has been reported that there was a significantly higher frequency and greater degree of positive remodelling, as well as a larger amount of necrotic core, non-calcified plaques in acute coronary syndrome as visualized on IVUS [18, 19]. However, the region of low echogenicity, which is believed to represent the composition of lipid-containing and mixed plaque, remains relatively uncharacterized by gray scale IVUS [17]. This limitation is overcome by the recent development of a novel technique called virtual histology (VH) IVUS.

VH IVUS is an advanced radio-frequency analysis of intravascular ultrasound signals which provides an in vivo opportunity to assess plaque morphology [20, 21]. VH IVUS has been shown to demonstrate 80% to 92% in vitro accuracy for identification of different types of atherosclerotic plaques [20]. Nasu et al. concluded that correlation of in vivo IVUS radio-frequency data analysis with histopathology shows a high accuracy for the classification of different types of coronary components [21]. VH IVUS may allow better detection of features associated with future plaque rupture, thus improving our understanding of the atherosclerotic disease behavior and progression according to the baseline plaque composition [22].
4. LESS INVASIVE IMAGING MODALITIES

A number of techniques ranging from chest radiography to CT, MRI, Doppler ultrasonography and nuclear medicine techniques, belong to the category of less invasive modalities when compared to the above-mentioned invasive techniques. Some of these procedures, such as radiography and CT, can be done within a very short time, while others, such as cardiac MRI and cardiac perfusion study, may be time-consuming. Because of the reduced invasiveness and increased diagnostic value in cardiovascular disease due to technological developments, these less-invasive imaging modalities are increasingly used in the assessment of cardiovascular disease with some of them being used as a reliable alternative to invasive examinations.

4.1. Chest Radiography

Conventional chest radiography continues to play a very important role in the diagnosis and management of cardiovascular disease. Chest radiographs provide information about heart shape and size, which may be affected by many factors (Fig. 3). Estimation of the heart chamber size is difficult due to the overlapping of the atria and ventricles. However, chest radiography is excellent in demonstrating the great vessels and vascular changes within the lung fields, which offer critical information regarding cardiac functions (Fig. 4).

The image quality of chest radiographs is affected by many factors such as patient posture, degree of inspiration, correct positioning, geometric factors, and exposure technique selection. These factors can be controlled by the medical imaging technologists. Factors that are not under the technologist’s control but can affect cardiac shape and size include patient body habits, bony thorax abnormalities, and pathological conditions such as pneumothorax or pulmonary emphysema. These factors should be taken into consideration when selecting appropriate imaging parameters so as to ensure optimum acquisition of chest radiographs.

Despite its limited diagnostic value in cardiac imaging, chest radiography is the most commonly performed procedure, and the importance of these basic radiographic principles to ensure the accuracy of diagnostic chest radiographs should not be underestimated by medical imaging technologists.

4.2. Electron Beam Computed Tomography

Electron beam computed tomography (EBCT) was developed in the early 1980s. It is regarded as an ultrafast or high-speed CT scanner as it made CT imaging of heart and coronary arteries feasible. EBCT differs from conventional CT systems with the immovable X-ray source that enables fast data acquisition in a very short time. High temporal
resolution (50–100 milliseconds) makes this technique well-suited for imaging the heart and coronary tree, with the capability of evaluating tiny abnormalities such as coronary calcium and plaques, even in the presence of the motion of a rapidly beating heart. The main clinical application of EBCT is in the detection and evaluation of calcification in the coronary arteries (calcium scoring), which is considered a risk indicator of coronary artery disease [23, 24]. It has significant value in determining calcium scores, which are associated with the degree and severity of coronary artery disease and thus assists in predicting the probability of future cardiac events [25].

The main limitation of EBCT is its inferior spatial resolution, which is between 1.5–3.0 mm. This restricts its diagnostic value to accurately evaluate the severity of coronary artery disease. After the arrival of MSCT scanners in the late 1990s, the use of EBCT became scarce and was eventually replaced by MSCT from 2003 onwards.

---

**Figure 3.** Chest radiography. Chest radiograph shows normal appearance of the heart and aorta. (Image courtesy of Dr Evelyn LM Ho, Consultant Radiologist, Imaging Department, Sime Darby Specialist Centre Megah Sdn. Bhd., Petaling Jaya, Malaysia.)

**Figure 4.** Chest radiography. Chest radiograph shows abnormal heart appearance in a patient diagnosed with hypertension with left ventricle enlargement. (Image courtesy of Associate Professor Yang Faridah Abdul Aziz, University of Malaya Medical Centre, Kuala Lumpur, Malaysia.)
4.3. Computed Tomography

The first clinical CT scanner was developed by Godfrey Hounsfield from the United Kingdom in 1973. It was immediately recognized as a very useful diagnostic imaging technique as it allows visualization of the cross-sectional views of the body structures. In the early 1990s, the introduction of helical or spiral CT scanners was considered a major breakthrough for CT technology. With spiral CT, the patient table is continuously moving and translated through the gantry while scan data are acquired simultaneously. Spiral CT scanning does not have misregistration problems or loss of anatomic details since the scan is performed in a single breath-hold, thus enabling acquisition of volume data. Images could be reconstructed at any position along the patient longitudinal axis, and overlapping image reconstruction could be generated (normally 50% overlap) to improve longitudinal resolution. Acquisition of volume data has become the very basis for applications such as CT angiography [26] (Fig. 5).

The introduction of MSCT is considered a major evolutionary leap in CT technology. By late 1998, all major CT manufacturers launched MSCT scanners capable of at least four slices per X-ray tube rotation. The total number of detector elements depends on the number of detector elements in the X-ray plane (700–900) times the number of rows of detectors (2 to 4, 8, 16, 64, or more rows), yielding the total detector elements in the range of 1,400–60,000 [27]. The MSCT scanner, with its cone-shaped beam and multiple slices per rotation, allows for acquisition of multiple slices during one gantry rotation. This difference along with the reduced gantry rotation time in the MSCT scanners, leads to a shorter scanning time and greater coverage of scanning volume per gantry rotation and provides superior image quality [28].

The advantages of MSCT technology include: (1) the ability to obtain a large number of thin slices resulting in greater spatial resolution in both axial and longitudinal directions. For example, isotropic volume data (cubic voxels) can be acquired with 64- or more slice CT, resulting in improved resolution of the volume data (images are equally sharp in

Figure 5. Abdominal multislice CT angiography. Multislice CT angiography shows an infrarenal aortic aneurysm (long arrows) with excellent demonstration of aortic branches from the abdominal aorta to external iliac arteries (short arrows).
any plane) (Fig. 6). This capability is obtained with multiple sections of submillimeter thickness. The speed can be used for fast imaging of a large volume of tissue with variable slice thickness. This is particularly useful in cardiac imaging studies and other studies where patient motion is a limiting factor such as in trauma or paediatric patients. With 4-slice CT and a gantry rotation of 0.5 s, the volume data can be acquired eight times faster than with the single slice, 1-s scanner. With 16- and 64-slice CT and rotation times of less than 0.5 s, the volume data are acquired at an even greater rate than that of early generation MSCT scanners (Fig. 7). With 256- and 320-slice CT, the entire heart can be covered in a single gantry rotation with a slice thickness of 0.5 mm or less [29, 30] (Fig. 8).

The most common application of MSCT is to detect hemodynamically significant coronary stenosis with high sensitivity and specificity (Fig. 9). The quality of MSCT coronary angiography improved significantly with the introduction of 16- and 64-slice CT systems and satisfactory results have been achieved [31–33]. Several meta-analyses of 64-slice CT
studies have reported moderate to high sensitivities and specificities with respect to coronary artery disease (CAD), and an extremely high negative predictive value (96–100%) [32–36]. Further technical developments, such as 256- and 320-slice CT scanners, allow longer z-axis coverage, ranging from 12.8–16 cm in one gantry rotation, which permits rapid scanning of the entire heart [29, 30].

MSCT has also been confirmed to be valuable in the diagnosis of many other cardiovascular diseases, and in some areas it has replaced invasive angiography due to its high diagnostic value. MSCT angiography has been reported to be superior to invasive angiography in the assessment of abdominal aortic aneurysm pre- and post-endovascular aneurysm repair [37, 38]. MSCT angiography has been shown to be more sensitive than invasive angiography, and it is the preferred method for diagnosis of aortic dissection with a sensitivity and specificity of nearly 100% [39, 40] (Fig. 10). As a reliable alternative to conventional pulmonary angiography, MSCT angiography has been recognized as the first line technique for detection and diagnosis of pulmonary embolism (Fig. 11). With the rapid developments of CT techniques, MSCT pulmonary angiography was initially used as an adjunct and an alternative to other imaging modalities. Recently, it has become widely recognized as the method of choice for diagnosis of suspected pulmonary

Figure 8. 320-slice CT coronary angiography. 3D volume rendering demonstrates the heart and coronary artery branches with data acquired in a single heart beat. Main coronary arteries and their side branches are clearly visualized.

embolism due to its superior sensitivity and specificity to ventilation-perfusion radioiso-
tope scanning [41–43]. MSCT angiography has demonstrated a high diagnostic value (more than 90% sensitivity and specificity) in the diagnosis of peripheral arterial disease when compared to invasive peripheral angiography [44]. Moreover, 64-slice CT angiography has been reported to have high sensitivity and specificity for the detection of significant in-stent or persistent restenosis in patients with peripheral artery stent implantation, and therefore is considered as a valuable non-invasive technique for stent evaluation and surveillance [45].

4.4. Magnetic Resonance Imaging

MRI provides excellent soft tissue contrast with inherent 3D capabilities and allows acquisi-
tion in any anatomical plane. Diagnosis of cardiac disease requires accurate assessment of both morphology and function of the heart and cardiovascular system. MRI is widely used to image patients with renal dysfunction or impairment which prevents them from undergoing contrast-enhanced CT scans. Cardiac MRI has recently gained popularity as a clinical diagnostic modality to evaluate many cardiac and great vessel abnormalities. It may be used to evaluate several important diagnostic features including cardiac morphology, regional and global ventricular function, myocardial fusion, and coronary artery flow and anatomy. Since the heart displays complex motion due to both cardiac contraction and respiration, the MRI pulse sequences should provide breath-hold or adequate respiratory-triggered acquisition as well as electrocardiography (ECG) gating acquisition. Contrast-enhanced MRI can demonstrate myocardial perfusion and blood flow velocities within the heart and cardiovascular system.

MRI has been widely applied in the diagnosis of various cardiovascular diseases with high diagnostic accuracy being achieved. There are several different imaging techniques...
Figure 11. Pulmonary CT angiography. Pulmonary embolism is shown at the bilateral pulmonary artery branches. A large thrombus is present in the left main pulmonary artery and it extends to the right side (top left image). Orthogonal views show that the viewing position is located in the pulmonary trunk (bottom row images). The intraluminal thrombus was demonstrated on virtual endoscopy image (arrows on the right top image).

for MR angiography, and the most suitable technique is contrast-enhanced MR angiography, which provides visualization of the heart and entire arterial vascular system. MRI is used to evaluate aortic aneurysms and is reported to be as accurate as CT angiography and invasive angiography for preoperative measurement of aneurysm size and extent [46, 47]. In patients treated with endovascular stent grafts, MRI has been shown to demonstrate changes in the aneurysm and in the stent-graft morphology, thrombus formation, periaortic inflammation, and vertebral body infarction [48, 49]. Contrast-enhanced MR angiography has been reported to be a feasible and accurate method to depict significant stenoses and occlusions in lower extremity arteries [50, 51]. Contrast-enhanced MR angiography was also found to demonstrate high diagnostic value in the diagnosis of carotid artery stenosis or occlusion, thus it could be used as an effective alternative to invasive angiography [52] (Fig. 12).

Recent technical developments in hardware and software as well as introduction of new imaging parameters has enabled MRI to become the standard of reference for functional evaluation of cardiovascular diseases such as evaluation of global cardiac function and perfusion [53, 54]. As such, MR angiography has replaced most of the invasive cardiac angiography examinations [55]. ECG-gated multiplanar fast gradient echo MRI is a technique for demonstrating morphology of the heart and great vessels. With this technique, bright blood images at different cardiac phases on multiple slice locations can be acquired within a single breath-hold. A complete cardiac MR examination consists of functional imaging of the left ventricular myocardium with the aim of detecting regional or global wall motion abnormalities, which can be caused by several diseases. Most of
these common abnormalities are caused by atherosclerosis-induced coronary artery disease due to insufficient blood/oxygen supply to the myocardium or myocardial scars following myocardial infarction [55]. Perfusion imaging of the myocardium that is performed at rest and with pharmacologically-induced stress allows analysis of the condition of coronary arteries [56]. Delayed contrast-enhanced imaging allows detection of myocardial infarction, scars, and otherwise structurally changed myocardium due to an increased interstitial space [57].

Several studies have shown the excellent diagnostic accuracy of MR myocardial perfusion imaging for detecting obstructive coronary artery disease when compared to invasive coronary angiography [58, 59], and hemodynamically significant CAD compared to invasive functional measurements [60, 61]. It has been reported that MR myocardial perfusion imaging is as accurate in demonstrating CAD as SPECT and of similar prognostic value [62–64]. Because MR myocardial perfusion imaging does not use ionizing radiation, it may serve as an ideal additional functional imaging technique along with coronary CT angiography for evaluating patients suspected of having CAD [65]. Recent studies have shown the improved diagnostic performance of combined coronary CT angiography and perfusion cardiac MRI when compared to invasive coronary angiography in the comprehensive workup of hemodynamically stenosed CAD [65, 66].

4.5. Doppler Ultrasonography

Doppler ultrasound is an adjunct, non-invasive procedure used to study the heart and peripheral vascular tree and corresponding abnormalities. Since the 1970s, it has become the mainstay of non-invasive imaging of blood flow through the heart and cardiovascular system by displaying flow data on the two-dimensional sonographic image. It is used to determine the direction and velocity, as well as the presence or absence of blood flow in both arteries and veins. With Doppler ultrasonography, the blood flow is not affected until any obstruction present is at least 50%. This technique is valuable in vascular imaging as it helps reveal physiological characteristics (blood flow pattern and velocity changes) and define anatomy such as plaque morphology (Fig. 13).

Color Doppler depicts local flow by color-encoding an estimate of the mean Doppler frequency shift at a particular position in color. It has the capability of identifying valvular, congenital, and other forms of heart disease, as the color flow image provides spatial information to the Doppler data. Color flow display makes the Doppler data more readily understandable because of the avoidance of complex spectral velocity displays. Power
Doppler has added a color Doppler mode that encodes the power rather than the velocity and direction of the Doppler signal [67, 68]. Power Doppler ultrasonography is able to improve the sensitivity to flow and provide better delineation of tortuous vessels due to its dynamic range and relative angle independence [69].

Doppler ultrasonography has been used widely for imaging the cardiovascular system, and the most common applications include evaluation of carotid artery stenosis and peripheral vascular disease [52, 70–72]. Doppler ultrasonography has been validated by several large multi-center randomized control trials investigating the treatment of occlusive carotid disease and is considered the gold standard technique [73–75]. This is confirmed by a recent study showing that Doppler ultrasonography is more accurate than CT in assessing the carotid artery disease, and is useful for evaluating patients with significant stenosis of the carotid tree [76]. A meta-analysis reported the diagnostic value of Doppler ultrasonography in peripheral arterial disease to have fairly good sensitivity (87.6%) and specificity (94.7%), but is inferior to MR angiography (97.5% and 96.2% for pooled sensitivity and specificity, respectively) [72].

Doppler ultrasonography has been considered to be a potentially attractive alternative to CT angiography in the follow-up of patients treated with aortic stent grafts, since ultrasound is less expensive and does not involve ionizing radiation or potentially nephrotoxic contrast [77, 78]. Color Doppler ultrasonography was inaccurate in the measurements of aneurysm diameters when compared to CT angiography [79], however, contrast-enhanced ultrasound improved the diagnostic value of Doppler ultrasonography for detection and evaluation of vessels in case of low flow, slow flow, or deep vessels [80]. Several studies have supported the use of contrast agents for increasing the sensitivity of color Doppler ultrasonography for detection of endoleak, the most common complication of endovascular repair or aortic aneurysms, although CT angiography still remains the modality of choice in the follow-up of patients with abdominal aortic aneurysm after endovascular repair [79, 81, 82]. With the prevailing concerns about increasing radiation dose and cost associated with CT scans, Doppler ultrasonography was recently shown to be a safe and effective tool in the monitoring of patients following endovascular repair [83]. Where Doppler ultrasonography is validated as sensitive and with high negative predictive value, it may replace CT angiography for follow-up of endovascular repair, with CT angiography reserved for cases of positive or inconclusive Doppler ultrasonography.
4.6. Echocardiography

Echocardiography comprises a group of non-invasive ultrasound procedures that can provide detailed information about heart anatomy, function, and vessel patency. Ultrasonographic imaging may be performed using M-mode, two-dimensional imaging, color Doppler, spectral Doppler, or stress echocardiography. Echocardiography is recognized as a highly valuable diagnostic modality for the evaluation of cardiac anatomy, function, and hemodynamics. As such, it is the most commonly used imaging procedure for the diagnosis of heart disease.

Quantification of cardiac chamber size, ventricular mass, and function represent the most clinically important and most frequently requested tasks of echocardiography. During the last decades, echocardiography methods and techniques have progressed rapidly with significant improvement in image quality because of the introduction of higher-frequency transducers, harmonic imaging, fully digital machines, use of contrast agents, and other technological advancements [84]. Furthermore, echocardiography has become the major cardiac imaging technique in emergency, operating, and intensive care departments due to its portability and versatility.

Echocardiography has been proven to be useful in many applications related to cardiac functional assessment. Doppler echocardiography helps the evaluation of diastolic function of the heart chambers by recording velocity changes that occur with variations in left atrial and left ventricle diastolic pressures [85, 86] (Fig. 14). Analysis of the pulmonary vein velocities can provide insight into the diastolic properties of the left ventricle and the function of the left atrium [87]. Tricuspid inflow velocity reflects the atrioventricular diastolic pressure-flow interactions on the right side of the heart, thus this can be measured with Doppler echocardiography to evaluate the right ventricle diastolic function [87]. In addition, Doppler echocardiography is the most commonly used diagnostic technique for detecting and evaluating regurgitant valve lesions, including assessment of regurgitant volume, regurgitant fraction, and effective regurgitant orifice area. Prosthetic valve function can also be evaluated by Doppler echocardiography by recording velocities through prosthetic valves [87].

5. NUCLEAR MEDICINE IMAGING MODALITIES

Although echocardiography, MSCT, and MRI typically are used to evaluate anatomic structures of the heart, they have limited capabilities in the assessment or visualization of physiological and metabolic processes. Conversely, SPECT and PET provide excellent
information about physiological and metabolic characteristics but are limited in their capability to visualize anatomical structures. By using anatomical imaging modalities combined with molecular imaging technologies such as SPECT and PET, it is possible to detect disease processes at the anatomical, physiological, metabolic, and molecular levels [88]. Therefore, this allows early detection of diseases, objective monitoring of therapies, and better prognosis of disease progression [89].

5.1. Single Photon Emission Computed Tomography

SPECT is composed of conventional scintigraphy and computed tomography techniques that present three-dimensional and functional information about the patient’s anatomy in more detail. Myocardial perfusion imaging (MPI) with SPECT is a widely established method for non-invasively evaluating the myocardial viability, left ventricular function, and coronary artery stenosis. SPECT has been used as a routine technique in the clinical practice for myocardial perfusion imaging for decades [90]. The most important applications of SPECT are in the diagnosis of CAD, prediction of prognosis, selection for revascularization, and assessment of acute coronary syndromes (Fig. 15). Moreover, SPECT has special value in some particular patient subgroups [91–94].

Many studies have reported the varying degree of diagnostic accuracy of SPECT for detection of CAD. Specificity varies among studies depending upon patient population, nature of reporting, and referral bias [95]. In the largest single study of 2560 patients randomized to each of the three radiotracers (thallium, MIBI, and tetrofosmin) and using mainly adenosine stress, overall sensitivity, and specificity in the subset of patients undergoing angiography was 91% and 87%, respectively, with no significant difference between the three tracers [96]. In general, the sensitivity of stress SPECT for detecting CAD defined by invasive coronary angiography is consistently above 70%, but in the better designed studies it is within the range of 85–90% [97–99]. Reported specificity varies from 33% to 100% but in the better quality studies it is within the range of 70–75% [99–101].

**Figure 15.** Cardiac SPECT. SPECT shows the myocardial perfusion defect in the left anterior coronary segment in a 63-year old woman with suspected coronary artery disease. (Image courtesy of Professor Mu-Hua Cheng, Chief of Department of Nuclear Medicine, Third Hospital Affiliated Sun Yat-Sen University, People Republic of China).
5.2. Positron Emission Tomography

PET is a powerful, quantitative imaging modality that has been used for decades to non-invasively investigate cardiovascular biology and physiology. Due to its inherently quantitative nature, its superior detection sensitivity, and its advantageous spatial and temporal resolution over conventional nuclear medicine techniques, PET has been considered a gold standard for non-invasive assessment of myocardial perfusion and viability. Nonetheless, the lack of widespread availability of PET scanners and radiotracers, its high cost, the limited data supporting its application, and reimbursement issues in some countries have all contributed to the limited clinical acceptance of PET as a routine diagnostic tool. However, recognition of the value of cardiac PET has been changing recently because of its widely accepted clinical role in oncology. This has led to an increase in the number of PET scanners installed worldwide, thereby creating opportunities for more cardiac applications.

PET has been reported to be valuable in the diagnosis of CAD as it allows for assessment of myocardial perfusion (Fig. 16). In an early review of eight studies consisting of a total of nearly 800 patients that compared perfusion PET with coronary angiography, results were summarized and a mean sensitivity and specificity of 93% and 92% was observed, respectively [102]. A more recent review from nine studies that looked at 877 patients, reported a weighted sensitivity of 90% and specificity of 89% with most of the scans performed with rubidium-82 (82Rb) [103]. For detection of myocardial ischemia, myocardial perfusion PET is considered to have superior diagnostic accuracy when compared with the more widely available and more frequently used SPECT technique [103]. Bateman et al. in their prospective study compared matched pharmacological stress patients and concluded that myocardial perfusion PET was superior to SPECT in image quality, certainty in interpretation, and diagnostic accuracy [94]. This was also confirmed by a recent study comparing PET with SPECT in two comparable patient cohorts with invasive coronary angiography as the gold standard. Husmann et al. reported that 13N-ammonia PET is more sensitive and specific in the detection and localization of coronary stenoses, and more specific in the detection of ischemia than SPECT [104].

Figure 16. Cardiac PET. Myocardial viability study using 18F FDG PET in a 47-year old man shows that the distribution of FDG is homogeneous and no defect is observed in the cardiac chamber. (Image courtesy of Associate Professor Abdul Jalil Nordin, Director, Diagnostic Nuclear Imaging Centre, University Putra Malaysia, Selangor, Malaysia.)
In addition to the high diagnostic accuracy, PET has been shown to demonstrate prognostic value with potential to predict adverse cardiac events [105]. Studies have shown that PET has an independent and prognostic value with increased annual mortality rate being associated with abnormal scans [105, 106]. A recent study confirmed the prognostic value of PET in 1441 patients with suspected or known CAD, and it demonstrated an incremental value of stress in the left ventricular ejection fraction from gated PET [107]. The ability to quantify myocardial blood flow and coronary flow reserve in absolute terms is another feature of unique PET imaging [108]. Quantitative flow measurements may be useful and complementary to the current standard of visual/semi-quantitative analysis. PET imaging may be useful for detection and evaluation of extensive multivessel CAD with balanced ischemia, evaluation of collateral flow, identification of endothelial dysfunction in pre-clinical disease, and reliable monitoring of therapeutic strategies [109–111].

Myocardial viability testing has been developed to serve as a guide to the most appropriate therapy in patients with advanced CAD and severe left ventricular dysfunction. PET has played a key role in understanding the myocardial response to severe ischemia damage and in establishing the identification of myocardial viability as a diagnostic target. It is well-known that PET with the use of the metabolic radiotracer FDG (fluorodeoxyglucose) is able to accurately predict improvement of regional wall motion and global left ventricular ejection fraction after revascularization. In a recent meta-analysis of 24 studies consisting of 756 patients, PET demonstrated a weighted mean sensitivity and specificity of 92% and 63%, respectively, for regional functional recovery [112]. The usefulness of PET in cardiac imaging has been supported by growing evidence, although more rigorous studies are needed to confirm its clinical value.

Recently, several reports have highlighted the potential role of PET for the assessment of various aortic diseases based on the FDG accumulation [113–117]. FDG PET findings can provide additional information for the diagnosis of aortic aneurysm [114], aortitis or periaortitis [115], Takayasu arteritis [116], intramural hematoma [117] and vascular graft thrombus and infection [92].

5.3. Hybrid Imaging Modalities

5.3.1. Hybrid Single Photon Emission Computed Tomography and Computed Tomography

More recently, integrated SPECT/CT scanners have become available, including systems combining a state-of-the-art multihed gamma-camera and MSCT scanner side by side with a common imaging table. Combined SPECT/CT provides both functional information from SPECT and anatomical information from CT in a single examination. Studies have demonstrated that the information obtained by SPECT/CT is more accurate in evaluating patients than that obtained from either SPECT or CT alone [118, 119]. Rispler et al. [120] used an integrated SPECT/CT scanner to identify the presence of coronary stenoses, and at the same time, determined their functional significance through myocardial perfusion imaging. Diagnostic performance of SPECT/CT, especially specificity and positive predictive value was found to be superior to CT and SPECT alone, thus hybrid SPECT/CT may induce physiology-based planning of interventional procedures in patients with demonstrated CAD.

Hybrid cardiac SPECT/64-slice CT is the latest technology that allows performing both myocardial perfusion SPECT and coronary CT angiography in a single session with subsequent co-registration of data obtained from each imaging modality into a fused image, thus enabling simultaneous evaluation of coronary artery anatomy and assessment of the physiological relevance of coronary stenosis. It has been shown that combined SPECT/CT provides a good assessment of the left ventricular function with good correlation to those determined by CT angiography or SPECT, with a very low inter-observer variability [121].
5.3.2. Hybrid Positron Emission Tomography and Computed Tomography

Despite improved diagnostic performance, the SPECT/CT scanner might not be sufficiently accurate to be established as the new diagnostic and therapeutic regime in patients with known CAD. Segments with coronary stenosis but normal SPECT still showed significantly reduced coronary flow reserve. Thus, it might be desirable to invest in hybrid PET/CT scanners, so as not to underestimate the extent of inducible cardiac ischemia. The advent of hybrid PET/CT has led to the unique opportunity to combine CT-derived morphological information with PET-derived functional, physiological, and biological information. Most PET/CT scanners are equipped with MSCT, allowing CT measurement of coronary calcium and coronary CT angiography for analysis of CAD in addition to PET imaging procedures.

Initial studies suggested that both CT coronary angiography and perfusion PET may be complementary rather than competitive, although more evidence is needed to confirm the value of integrated modalities [118]. Integrated PET/CT provides an opportunity to assess the presence and magnitude of subclinical atherosclerotic disease burden, and measure myocardial blood flow as marker of endothelial health and atherosclerosis disease activity [119]. Contrast-enhanced CT enables the detection of non-calcified or vulnerable plaque; however, this information is best combined with PET imaging as PET/CT offers insights into atherothrombotic processes, better risk-stratification, optimal selection of therapeutic targets, and the effective means for monitoring therapeutic responses [122].

PET/CT has been shown to have high diagnostic performance in the detection of obstructive atherosclerosis among patients with suspected CAD. Sampson et al. [123] reported that diagnostic sensitivity of PET/CT in patients with single-vessel disease was 92% higher than that reported with conventional techniques [124], while the specificity of PET/CT was comparable with that reported in previous studies using PET alone (83% vs 86%) [91, 125]. In addition, the diagnostic sensitivity was equally high in obese and non-obese patients (mean BMI >30 kg/m²). Similarly, Santana et al. [126] applied a newly developed normal database and criteria in a prospective population to test the diagnostic accuracy of database quantitative PET/CT. The quantitative approach was validated in their study with high accuracy achieved for the detection and localization of CAD. They recommended that physicians consider using the quantitative method in their study as decision support tools to aid with image interpretation.

6. IONIZING RADIATION EXAMINATIONS-RADIATION DOSE ISSUE

Globally, the use of ionizing radiation in medical application has increased significantly. It is being used daily for imaging of patients in more than 10 million diagnostic radiology procedures and 100,000 diagnostic nuclear medicine procedures worldwide [127]. It is also used daily for radiotherapy of patients as well as many therapeutic nuclear medicine procedures. It has proven to be able to bring tremendous medical benefits to mankind. However, as ionizing radiation is associated with risks due to stochastic and non-stochastic effects, it is essential to consider the protection of patients from potential harm resulting from the use of ionizing radiation.

The main issue in radiation protection of patients is the rapidly increasing collective dose to patients from medical exposure. This is due to the rapid increase of new technologies for medical exposure, and the corresponding speed at which these technologies are adopted into clinical practice. In particular, the increased use of CT with associated high radiation dose is an example of a clear and prominent upward trend [128]. Other current important directions include increased awareness of radiation risks from both health care professionals and the public, inappropriateness of a substantial number of diagnostic imaging examinations performed, as well as recurring safety issues in interventional and therapeutic procedures.
6.1. Radiation Doses Relevant to Cardiac Angiography and Associated Interventional Procedures

The hazards associated with cardiac angiography and associated interventional procedures are well documented in the literature, with effects ranging from mild erythema to skin ulceration and necrosis [129–140]. In regional and national legislative documents [141, 142], the need to focus on such high dose examinations is acknowledged so that regional variations can be highlighted, causal agents for such variations can be identified, and appropriate corrective action put into place wherever possible. With interventional procedures in general it is often quite rightly argued that many of the patients undergoing these procedures are very ill and require these procedures for palliative effects. In cardiac procedures, however patients are often relatively young and once interventional procedures are performed they can live healthily for many years, underlining the importance of dose optimization if adverse radiation-induced side-effects are not to be experienced.

Radiation doses can vary substantially across the same cardiac angiographic and interventional procedures, which is often a result of varying complexities of examination or patient size, but can be a consequence of technological or procedural preference. In a recent study involving almost 2,000 cardiac procedures [143], a regression analysis demonstrated that the most important causal agent for dose variations (as with many other fluoroscopic examinations) was fluoroscopic time. This factor alone accounted for 61%, 59%, 44%, and 37% of the dose variation seen for percutaneous coronary intervention, permanent pacemaker insertion, coronary arteriography, and coronary arteriography with percutaneous coronary intervention procedures, respectively. Other factors identified as being responsible for variations in dose included patient body mass index, complexity of procedure, cine run time, number of previous grafts, number of stents, and experience of operator.

The relevance of diagnostic reference levels (DRLs) to cardiac procedures is debatable. DRLs are radiation dose values for specific examinations that should not be consistently exceeded when good practice is in place and if regularly exceeded remedial action should be sought. These are legal requirements in a number of jurisdictions [141, 142], and have been shown to be very effective in reducing dose and dose variations for a variety of investigations since their introduction two decades ago. It is often argued that DRLs cannot work for cardiac procedures since patient size variations and complexity of examinations mean that variations will always exist and these would be difficult to control. Indeed, excessive standardization of doses may be at the detriment of the patient. The counter-argument to this is that since fluoroscopic time is the main variable and this is shown to vary significantly for other much less complex examinations, operator preference may well be a factor in these dose variations. Also, DRLs can be set for groups of specific patient sizes. Clearly, further work is required to explore the relevance and application of DRLs for cardiac procedures and to establish if such complex factors, such as operator practices, can be standardized to some extent.

Collective dose is also another issue. While the individual doses as shown above are high, due to the cost effectiveness, low patient morbidity, and the opportunity for such examinations to be performed on a day-case basis, cardiac angiography and associated interventional procedures are increasingly popular. In a population such as the UK, in a single year, over 162,000 cardiac angiography cases are performed in addition to almost 122,000 cardiovascular interventions. These data were presented in 2002 and it is likely that these numbers are on the increase. Whatever the precise numbers are at the time of this publication, the product of these procedural numbers and the radiation dose per examination suggest that cardiac angiography procedures contribute significantly to the average annual radiation dose delivered to an individual within a given population where these examinations are performed regularly.

In summary, while cardiac angiographic procedures are of huge clinical value, good optimization and justification procedures should be in place. Doses delivered often exceed the threshold of non-stochastic effects and present significant stochastic risk to
patients and staff. Dose optimization and standardization of procedures should be implemented to maximize the investigative and therapeutic benefit for patients who undergo such procedures.

6.2. Chest Radiography

Chest radiography is the most commonly performed x-ray examination in clinical practice. Chest radiographs are valuable for solving a variety of clinical problems, and serve as the first line diagnostic technique for determining further steps in the establishment of a diagnosis, treatment, and follow-up procedure [144]. Although individual patient dose in chest radiography is relatively low, its contribution to the collective dose is significant due to the frequent use of this examination. About 30–40% of all diagnostic x-ray examinations are reported to be chest radiography [145–147]. The associated estimated contribution to the collective dose is about 18% [145]. Thus, optimization of image quality and radiation dose in chest radiography is an important ongoing activity.

In the past decades a shift has occurred from the principle of ‘image quality as good as possible’ to ‘image quality as good as acceptable.’ Radiation dose to patients should be ‘as low as reasonably achievable’ (ALARA), while still providing diagnostic image quality [148, 149]. Dose reduction of up to 50% can be achieved by adjusting the imaging parameters such as tube voltage or tube current without compromising diagnostic performance [150, 151]. Therefore, optimization of chest radiography should comprise a significant component of good routine clinical practice.

6.3. Computed Tomography

Although CT represents 10–15% of all X-ray examinations, it contributes up to 70% of the radiation exposure. Radiation dose is becoming a major issue for MSCT angiography, since 64- or more-slice CT shows improved diagnosis of CAD [152, 153]. It is estimated that in daily practice, the effective dose of cardiac MSCT angiography may reach up to 40 mSv in female patients if no dose optimization strategies are applied, and this is associated with radiation exposure to breast tissues. Cardiac patients may also be exposed to other sources of medical radiation (including from nuclear medicine and invasive coronary angiography examinations). With repeated examinations and the cumulated radiation dose, radiation exposure has become a definite risk to patients. Given the fact that CT is a high-dose imaging modality, it is critical to minimize the radiation dose associated with cardiac CT examinations.

Two recent studies published in the Archives of Internal Medicine highlighted the importance of standardization of common CT examinations including cardiac CT imaging, as well as the cancer risk associated with radiation [154, 155]. Smith-Bindman et al. [154] analyzed the radiation doses for the most commonly performed CT examinations at four institutions and found a surprising variation in radiation dose—a mean 13-fold variation between the highest and lowest dose for each CT examination studied (range, 6- to 22-fold difference across study types). The researchers estimated that 1 in every 270 40-year-old women undergoing a CT coronary angiogram will develop cancer from the procedure. In another study, de Gonzalez et al. [155] estimated that CT scans done in 2007 could have led to 29,000 excess cancers. These cancers will appear in the next 20 to 30 years and according to their estimation, at a 50% mortality rate, will cause approximately 15,000 deaths annually.

Radiation-induced malignancy is a problem that has been addressed by the National Research Council of the United States [156]. It is reported that radiation dose from a CT examination has been significantly underestimated by the radiologists and physicians [157, 158]. Despite the increased awareness of radiation risk, they have not realized the amount of radiation exposure associated with cardiac CT and the possibility of optimizing the scanning protocols to reduce radiation dose. An international, multicenter study of 50 study sites, looking at estimated radiation dose during cardiac CT angiography, has shown a wide range of median effective dosea that ranged from 5 to 30 mSv [159]. The
study also indicated that radiation exposure can be reduced substantially by implementing available strategies for dose reduction; however, these strategies are not frequently used in clinical practice.

Recently tremendous progress has been made to lower radiation dose for cardiac MSCT angiography, and various strategies have been proposed to address this issue. Readers are referred to some excellent review articles with regard to the dose reduction and justification of the use of MSCT in cardiac imaging [160–162]. In addition, the benefits of using coronary MSCT angiography in the diagnostic workup and patient management must be weighed against the potential risks related to radiation exposure.

In summary, radiation exposure associated with cardiac MSCT angiography has increased substantially over the past two decades, and it is a major concern that requires the attention of both clinicians and manufacturers. Radiation exposure is especially important for young, female patients who present with atypical symptoms, but do not have high pre-test likelihood for actually having hemodynamically significant coronary stenosis. Cardiac CT angiography should be performed with dose optimization strategies whenever possible to reduce the radiation dose to patients. MSCT scanning protocols in cardiac imaging should be standardized across institutions with the aim of reducing dose variation across patients and facilities. Physicians need to follow guidelines, such as the national DRL, for dose optimization, and they are encouraged to participate in radiation dose registry to obtain feedback on radiation dose levels when compared to other institutions. Utilization of cardiac MSCT angiography must be defined as to whether it leads to the greatest benefit and whether the radiation risk may be greater than the benefit expected from the CT examinations.

6.4. Nuclear Medicine Imaging

The medical use of ionizing radiation and radionuclides contributes significantly to the radiation exposure of individuals and populations. It has become common to quantify the patient’s exposures in terms of the effective dose [163]; however, in nuclear medicine imaging, the radiation dose can only be assessed indirectly via known amounts and types of administered radiopharmaceuticals. Overall, the diagnostic practice with radiopharmaceuticals accounts for a small proportion of all radiological examinations with the annual number of nuclear medicine examinations and their collective doses representing only 2% and 6%, respectively, of the corresponding values for X-ray examinations. However, the mean dose per procedure for nuclear medicine imaging (4.6 mSv) is higher than that for conventional X-ray examinations (1.2 mSv) and similar to that for CT scan (2–8 mSv) [164, 165]. Thus, this collective dose arising from nuclear medicine examinations allows evaluation of the additional risk of radiation-induced malignancy.

Nuclear medicine imaging is different from other imaging modalities as medical staff, especially nuclear medicine technologists, are at potential risk of exposure to ionizing radiation while carrying out a variety of tasks associated with each nuclear medicine

<table>
<thead>
<tr>
<th>Examination</th>
<th>Average effective dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest radiography-Posteroanterior and lateral</td>
<td>0.05–0.24</td>
</tr>
<tr>
<td>Cardiac CT angiography (retroscopic gating)</td>
<td>7.6–31.8</td>
</tr>
<tr>
<td>Cardiac CT angiography (prospective gating)</td>
<td>1.7–12.6</td>
</tr>
<tr>
<td>Electron beam CT</td>
<td>0.6–1.3</td>
</tr>
<tr>
<td>Cardiac SPECT (rest + stress)</td>
<td>8.5–14.4</td>
</tr>
<tr>
<td>Cardiac PET (rest + stress)</td>
<td>2.2–7.0</td>
</tr>
<tr>
<td>Cardiac SPECT/CT</td>
<td>24.1–41.5</td>
</tr>
<tr>
<td>Cardiac PET/CT</td>
<td>5–20</td>
</tr>
<tr>
<td>Whole body PET/CT</td>
<td>20–25</td>
</tr>
<tr>
<td>Diagnostic cardiac angiography</td>
<td>2–9</td>
</tr>
<tr>
<td>Percutaneous cardiac intervention</td>
<td>15.0</td>
</tr>
</tbody>
</table>
procedure. Many studies have demonstrated that the exposure of nuclear medicine technologists arises mainly from radioactive patients rather than from the preparation of radiopharmaceuticals [166–168]. Various measurements of technologists’ exposure have been proposed and methods are recommended with the aim of reducing the radiation exposure during routine nuclear medicine procedures [169–172]. In addition, with combined imaging modalities such as SPECT/CT or PET/CT, the radiation dose to the patient is the combination of the radiation dose from the SPECT or PET radiopharmaceuticals, as well as the radiation dose from the CT portion of the study.

Table 1 shows the average effective dose for various imaging modalities reported in the literature.

7. SUMMARY AND CONCLUSION

Medical imaging techniques play an important role in the visualization and diagnosis of cardiovascular diseases. As mentioned above, these techniques range from conventional radiographic imaging such as chest radiography to advanced modalities such as MSCT in cardiac imaging and PET or PET/CT imaging. Rapid technological developments of imaging modalities have challenged the conventional invasive angiography procedure since less-invasive modalities offer high diagnostic accuracy for detection and diagnosis of a variety of cardiovascular diseases. In some areas, invasive angiography has been replaced by less-invasive modalities such as in the diagnosis of abdominal aortic aneurysm, pulmonary embolism, and peripheral arterial disease where MSCT angiography offers superior diagnostic performance over invasive angiography. In the diagnosis of CAD, MSCT angiography demonstrates promising results due to its increased performance with 64- or more slice CT, although presently MSCT has not reached the diagnostic accuracy to replace invasive coronary angiography. In particular, the very high negative predictive value of MSCT angiography indicates that it can be used as a reliable screening modality for patients with suspected CAD.

Functional imaging modalities, such as SPECT and PET, are increasingly used in the assessment of myocardial perfusion with the aim of predicting disease progress and providing prognostic information which is valuable for patient management. Combined functional imaging and anatomical modality, such as PET/CT, is developing and will play an increasing role in the assessment of cardiovascular diseases by maximizing the performance of each individual modality. Another advantage of functional imaging is its ability to provide molecular imaging, which will influence the management and improve understanding of the major cardiovascular diseases that have substantial clinical impact and research interest. This area is fast-growing, and more research outcomes are anticipated to be published in the near future.

Despite promising results having been achieved with these imaging modalities, attention must be paid to the limitations or disadvantages associated with each modality. Most importantly, radiation dose is a major issue that has raised serious concern in the medical field. Therefore, clinicians need to be aware of the potential risks associated with radiation exposure to patients and justify the selection of imaging modalities for diagnostic and management purposes.

REFERENCES


