Role of cardiovascular magnetic resonance in assessment of acute coronary syndrome

Shah M Azarisman, Karen S Teo, Matthew I Worthley, Stephen G Worthley

Abstract
Cardiovascular disease (CVD) is the leading cause of death in the western world and is becoming more important in the developing world. Recently, advances in monitoring, revascularisation and pharmacotherapy have resulted in a reduction in mortality. However, although mortality rates have declined, the burden of disease remains large resulting in high direct and indirect healthcare costs related to CVDs. In Australia, acute coronary syndrome (ACS) accounts for more than 300,000 years of life lost due to premature death and a total cost exceeding eight billion dollars annually. It is also the main contributor towards the discrepancy in life expectancy between indigenous and non-indigenous Australians. The high prevalence of CVD along with its associated cost urgently requires a reliable but non-invasive and cost-effective imaging modality. The imaging modality of choice should be able to accelerate the diagnosis of ACS, aid in the risk stratification of de novo coronary artery disease and avail incremental information of prognostic value such as viability which cardiovascular magnetic resonance (CMR) allows. Despite its manifold benefits, there are limitations to its wider use in routine clinical assessment and more studies are required into assessing its cost-effectiveness. It is hoped that with greater development in the technology and imaging protocols, CMR could be made less cumbersome, its imaging protocols less lengthy, the technology more inexpensive and easily applied in routine clinical practice.

INTRODUCTION
Cardiovascular disease (CVD) is the leading cause of death in the western world and is becoming more im-
Azarisman SM et al. CMR role in assessing ACS

Figure 1 Cascade of events following coronary artery occlusion. (Adapted from Gani et al[15]). ECG: Electrocardiography.

The regional and global ventricular function, what is the extent of myocardial necrosis, is there any viable myocardium and are the epicardial coronary arteries patent?\(^{10-12}\)

Over the past two decades, noninvasive imaging has emerged as the investigative modality of choice for ACS. It allows comprehensive cardiac assessment of patients, risk stratification of patients with ACS at an early management time point and provides diverse and complimentary information regarding possible differential diagnoses and prognosis.\(^{13-15}\)

NONINVASIVE ASSESSMENT

Early coronary reperfusion following diagnosis of ACS results in myocardial salvage and prevents irreversible injury.\(^{10,17}\) Usual investigative tools such as ECG and Troponin assays are helpful but may be negative early. Echocardiography, although useful in establishing regional wall motion abnormalities and quantifying ventricular ejection fraction, can also be negative early as these abnormalities appear later in the temporal cascade of events following coronary artery occlusion (Figure 1). Furthermore, echocardiographic assessment lacks the tissue characterisation ability needed to rule out differentials such as myocarditis. Over the past two decades, computed tomography (CT) has emerged as a potentially useful imaging modality for ACS.

COMPUTED TOMOGRAPHY BASED IMAGING

Positron emission tomography

Positron emission tomography (PET) utilises several radionuclides namely \( ^{18} \text{F-Fluorodeoxyglucose} \) (\(^{18}\text{FDG}\)) for myocardial metabolism and \( ^{13} \text{N-Ammonia} \) (\(^{13}\text{NH}_3\)) for myocardial perfusion assessment\(^{18}\). Myocardial segments with normal glucose metabolism and preserved myocardial flow indicate viable and adequately perfused myocardium. \(^{18}\text{FDG}\) allows differentiation between hibernating but viable, with infarcted and non-viable myocardium in regions with wall motion abnormalities when interpreted together with \(^{13}\text{NH}_3\).\(^{19,20}\) Although clinically useful in identifying metabolism/perfusion mismatch in stable CAD, its utility in the setting of ACS is limited due to restricted availability, high costs, and limited data supporting its application\(^{21}\).

Coronary angiography

Computed tomography coronary angiogram (CTCA) is becoming a useful tool for evaluation of patients with ACS. It can be utilised both in the diagnosis and risk stratification of ACS\(^{22,23}\). Three recent trials affirmed the utility of employing CTCA for rapid triage and radiographic demonstration of the absence of coronary artery disease in low to intermediate risk patients\(^{24,26}\). Whilst all three trials reported more rapid and cost efficient discharge from the Emergency Department with the use of CTCA, the CT-STAT and ROMICAT II trials reported an increase in downstream testing and radiation exposure.

ACUTE CORONARY SYNDROME

It is well established that ACS refers to a spectrum of clinical presentations ranging from unstable angina to non ST-elevation myocardial infarction and ST-elevation myocardial infarction. These presentations refer to clinical symptoms compatible with myocardial ischaemia resulting from acute thrombosis induced by a ruptured or eroded atherosclerotic coronary artery plaque\(^{1-4}\).

The main management strategy for ACS is prompt diagnosis leading to early coronary reperfusion. The usual assessment sequence involves a detailed case history delineating the patient’s risk factor profile, appropriate physical examination, electrocardiography (ECG) and laboratory risk markers such as creatine kinase and troponin levels.

Early reperfusion limits the final infarct size, halts progression of myocardial necrosis and optimises myocardial salvage thereby improving both short and long term outcomes\(^{8,9}\). Pertaining to these established aims, several questions need to be answered. What is the regional and global ventricular function, what is the
with no decrease in the overall costs of care \cite{25,26}. Although the appropriate use criteria endorses its use in low to intermediate risk patients, it is primarily an exclusion tool with limited suitability for higher cardiac risk patients or pathological stress testing \cite{27}.

**Calcium score**
Coronary artery calcification can be evaluated by electron beam CT and multi-detector CT. It describes the extent of coronary arteriosclerosis and is correlated with increased cardiac risk. It has a high negatively predictive value, and can reliably exclude ACS in low to intermediate risk patients presenting with chest pain \cite{28,29}. Unfortunately, its positive predictive value is unsatisfactory and a positive result usually warrants further downstream investigation. Moreover, conclusive evidence on its use in conjunction with other CT modalities such myocardial perfusion imaging (MPI) is still deficient \cite{30-32,35}.

**MPI**
Rest MPI becomes abnormal at the onset of impaired myocardial blood flow and therefore precedes other symptoms and signs of ACS. The non-invasive detection of a resting perfusion defect can be achieved with single-photon emission CT (SPECT), PET, cardiovascular magnetic resonance (CMR) and contrast enhanced echocardiography \cite{32-34,36}.

Resting myocardial perfusion is preserved with increasing severity of coronary stenosis through autoregulatory mechanisms in the microcirculation. This is exhausted when critical coronary artery stenosis develops and a resting myocardial perfusion abnormality will appear with complete occlusion of the coronary artery \cite{28-30,35}.

Cardiac CT based MPI has been utilised in animals since the late 1970s but its use in detection of MI only took off in mid-2000 \cite{31-34,36}. Resting MPI in addition to CTCA improves its diagnostic accuracy for detecting significant coronary artery disease. Studies have shown that in patients with chest pain, MPI with CTCA helps clarify the diagnosis of ACS \cite{14,31}. Unfortunately rest MPI is not sensitive enough to identify the majority of ischaemic segments and vasodilator-induced hyperemia is required to detect significant disease \cite{42-44}.

Stress MPI detects the presence of a flow-limiting coronary stenosis by detecting regional variations in perfusion reserve. During vasodilator-induced hyperaemia, blood flow will not increase in already dilated arteriolar bed of stenosed coronary arteries. However, perfusion of normal coronaries will increase significantly and the resultant increase over resting blood flow is referred as the perfusion reserve. Consequently, the perfusion reserve of normal coronary territories will be greater than that of critically stenosed coronary territories and this regional discrepancy is detected by stress MPI \cite{28-30,35}.

Stress MPI is especially helpful in patients with coronary calcification and stents, with studies reporting a sensitivity and specificity of at least 95% \cite{15,45}. Most studies however, report a sensitivity of between 50%-90% and specificity of 50%-98% when compared with either SPECT, CMR or invasive fractional-flow reserve (FFR) studies \cite{32,45-49}.

The major limitation to CT based rest and stress MPI, as with other CT based modalities, especially in research with comprehensive protocols remains exposure to ionizing radiation. Lack of long-term follow-up data of patients presenting to Emergency Department with chest pain and subsequently diagnosed with ACS is also compelling. Furthermore, although more recent studies have shown greater ability of different CT-based modalities in diagnosing and risk stratifying ACS, their utility remains only with those in the low to intermediate risk group. Cost effectiveness also becomes questionable with greater need for downstream investigation and greater overall cost of care especially in those with moderate to high risk of ACS.

**Magnetic resonance imaging**
In an Emergency setting, accurate early diagnosis of ACS along with efficacious institution of treatment is the main objective. As aforementioned, ECG and biomarkers are all helpful but may not be able to pick out early or equivocal ACS. Furthermore, these tests are presently unable to distinguish with certainty, ACS from other potential differentials, establish the extent of myocardial involvement, determine whether the damage is reversible, or even define the culprit artery with any reliability.

CMR offers high spatial resolution, accuracy and high reproducibility thereby allowing detailed volume and functional assessment, excellent tissue characterization in any tomographic plane and exceptional prognostic ability with late gadolinium enhancement (LGE) imaging (Figure 2). Radiation free examination also affords the CMR with the ability to incorporate extensive imaging protocols and repeated imaging necessary for both clinical and research imperatives.

Studies have already shown that CMR techniques such as myocardial function, perfusion imaging and LGE is able to provide a more accurate diagnosis of ACS compared with standard clinical assessment that includes ECG and biomarkers \cite{41}. The use of new imaging techniques such as T2-weighted sequences for oedema detection also increases its diagnostic performance \cite{50}.

Moreover, unlike CT-based imaging, CMR utility can be extended to patients with intermediate to high risk for ACS but without ECG or biomarker evidence of MI \cite{51}.

In essence, CMR represents a “one-stop-shop” for early and comprehensive assessment towards accurate and reliable diagnosis, risk stratification and prognostication of patients with ACS.

**Standard magnetic resonance imaging techniques**
Rest cine magnetic resonance imaging utilises steady-state free precession sequences to acquire a series of consecutive, breath-hold, long and short-axis slices (Figure 3). The excellent spatial resolution, coupled with the high contrast between blood and myocardium allows the en-
T2-weighted imaging

T2-weighted (T2W) imaging with short tau inversion recovery (STIR) sequences is used to detect myocardial oedema which has increased signal intensity. The presence of oedematous myocardial segments on T2W imaging is a sign of ischaemic myocardium and a negative prognostic indicator for cardiovascular events \[^{62}\]. Oedematous segments also allow acute-on-chronic differentiation of myocardial segments in established CAD patients \[^{63}\].

Acutely, T2W imaging also identifies the area-at-risk (AAR) which is defined as an area of potentially reversible myocardial injury but at risk of infarction. The extent of the AAR has been validated against histopathological and angiographic measurements and is predictive of the risk of further cardiovascular event or death \[^{62,64-66}\].

Perfusion imaging

Perfusion imaging is performed both at rest and stress (with Adenosine infusion) and assesses myocardial blood flow by capturing the transit of contrast medium through the cardiac border to be detected easily. This allows easy assessment of ventricular wall motion, ventricular volumes, ejection fraction, myocardial mass and anatomy of the extracardiac structures. These CMR assessments are accurate, reproducible and well validated \[^{54,55}\].

In the Emergency Department, these initial CMR imaging sequences can also be utilized to detect diseases of the aorta that may mimic ACS such as dissection or penetrating ulcer \[^{56}\]. Findings typical of myocarditis and Takotsubo cardiomyopathy can also be seen and confirmed by LGE \[^{57-60}\]. Initial review of the right ventricle and ventricular outflow tract, interventricular septum and pulmonary vasculature may also yield signs characteristic of acute pulmonary embolism which can then be subsequently confirmed with MR angiography \[^{61}\].

Figure 2 Cardiovascular magnetic resonance imaging sequence employed for the diagnosis of acute coronary syndrome. T2W: T2-weighted.
the myocardium. It is a well established tool for assessing acute impairment in myocardial blood flow, patency of microvasculature, myocardial perfusion reserve and viability\(^{[51,67]}\). In patients with chest pain with intermediate to high probability of ACS and a paucity of ischaemic signs, stress perfusion has a high negative predictive value with high diagnostic and prognostic value\(^{[53,68]}\).

CMR perfusion imaging is a potential alternative to CT-based perfusion imaging due to improved subendocardial resolution, lack of ionizing radiation and cost effectiveness with reduced downstream investigation. Comparison with SPECT, PET and/or coronary angiography have shown good sensitivity and specificity of CMR in detecting perfusion defects of 87%-90% and 85%, respectively\(^{[69,70]}\). Rest and stress perfusion imaging is well complemented by LGE and adds to a comprehen-

Figure 3 Standard imaging technique showing cine magnetic resonance imaging long axis views (A-C) and followed by short axis (D-F) and RVOT (G). Half-Fourier acquisition single-shot turbo spin-echo image shows the main, left and right pulmonary arteries (H).

Azarisman SM et al. CMR role in assessing ACS
sive assessment of patients with ACS. Its utility, reliability and accuracy in patients with intermediate to high risk of ACS also puts it ahead of CT-based perfusion studies.

**LGE**

Gadolinium based contrast is an extracellular contrast agent that accumulates in the interstitial space following myocardial death and replacement with fibrosis. Increased signal intensity denotes myocardial injury and scarring. Positive gadolinium enhancement coupled with CMR’s high spatial resolution allows accurate and reliable quantification of the volume of injury and the transmural extent of the scarring. This is crucial in estimating the extent of the scar as a percentage of wall thickness with ramifications towards viability and therefore, reversibility of the underlying myocardial dysfunction.

LGE essentially differentiates between irreversibly damaged (and thus non-viable) myocardium, from stunned myocardium which is ischaemic but viable. Acutely ischaemic but viable myocardium will have high signal intensity on T2W imaging but will be LGE negative. Generally, in a patient with MI, a transmural extent of scarring greater than 50% will signal a poor likelihood of functional recovery following revascularization. This has an important clinical ramification, as the prevalence of non-viable myocardial segments subtending the occluded epicardial artery will negate the need for immediate revascularization in an emergency setting.

LGE also has a role earlier in the diagnostic milieu of ACS by differentiating between ischaemic and non-ischaemic causes of chest pain with biomarker rise. Differentials such as myocarditis and cardiomyopathy will have a different pattern of hyperenhancement. Ischaemia typically causes a more coalescent and subendocardial distribution of gadolinium enhancement confined to a particular vascular territory. Myocarditis has a typically epicardial or mid-myocardial distribution and cardiomyopathy has a patchy, mid-wall distribution (Figure 4).

LGE is also used in identifying microvascular obstruction (MVO) which is known angiographically as the “no reflow” phenomenon. Pathologically it is caused by failure of reperfusion at a microvascular level despite patent coronary arteries following revascularization. It is seen as a hypoenhanced core surrounded by hyperenhanced, scarred myocardium. MVO is well established as a negative prognostic marker and has been shown to be predictors of adverse remodeling following myocardial infarction.

On another note, LGE is also of use for the detection of left ventricular (LV) thrombus which is a serious complication post-MI. It has a higher sensitivity and specificity than echocardiography for the detection of LV thrombus especially laminar, mural and apical thrombi.

**Prospect for clinical studies**

CMR is already the gold-standard imaging modality for assessing left ventricular volumes, ventricular function and tissue characterization in cardiomyopathies. These factors along with infarct size and MVO are common surrogate end-points in many clinical trials and strong
predictors of clinical outcome. Other imaging sequences coming to the fore include T1 relaxation times with modified look-locker imaging, myocardial tagging and phase contrast imaging for flow assessment. These sequences are especially pertinent in assessing diastolic function which is becoming more routinely assessed and thus gaining greater importance in post-MI imaging.

Limitations of CMR

The main obstruction to incorporating CMR as a routine assessment for ACS in Emergency Department is the high capital outlay required both in terms of hardware and human resource. This limits the CMRs ability to accommodate emergency studies in an Emergency Department setting despite the manifold benefits that it offers. Likewise, newer imaging protocols introduced as part of clinical studies may lengthen the scan time beyond what is acceptable for revascularization targets and thus rule out its relevance in the Emergency setting. Having a strong magnetic field also negates its use in patients with metallic implants, aside from those who are claustrophobic. It is also not as mobile and easy to use as an echocardiogram and thus may not be usable in an intensive care unit setting for those who may gain the most from its use. More research is required into establishing the cost-effectiveness of CMR in routine clinical practice.

CONCLUSION

CMR allows comprehensive assessment of patients presenting to the Emergency department with chest pain. Its ability to accurately and reliably diagnose, risk stratify and prognosticate ACS puts it ahead of other imaging modalities currently available. Despite its manifold benefits, there are limitations to its wider use in routine clinical assessment and more studies are required into assessing its cost-effectiveness. It is hoped that with greater development in the technology and imaging protocols, CMR could be made less cumbersome, its imaging protocols less lengthy, the technology more inexpensive and easily applied in routine clinical practice.

REFERENCES

1. Hamm CW, Bassand JP, Agewall S, Bax J, Boersma E, Bueno H, Caso P, Dudek D, Gielen S, Huber K, Ohman M, Petrie MC, Sonntag F, Uva MS, Storey RF, Wijns W, Zahger D. ESC guidelines for the management of acute coronary syndromes in patients presenting without persistent ST-segment elevation. The Task Force for the management of acute coronary syndromes (ACS) in patients presenting without persistent ST-segment elevation of the European Society of Cardiology (ESC). G Ital Cardiol (Rome) 2012; 13: 171-228 [PMID: 22395108 DOI: 10.1714/1038.11322]

2. Wright RS, Anderson JL, Adams CD, Bridges CR, Casey DE, Ettinger SM, Fesmire FM, Ganiats TG, Jneid H, Lincoff AM, Peterson ED, Philipsides GJ, Theroux P, Wenger NK, Zidar JP, Anderson JL, Adams CD, Antman EM, Bridges CR, Califf RM, Casey DE, Chavey WE, Fesmire FM, Hochman JS, Levin TN, Lincoff AM, Peterson ED, Theroux P, Wenger NK, Zidar JP. 2011 ACCF/AHA focused update incorporated into the ACC/AHA 2007 Guidelines for the Management of Patients with Unstable Angina/Non-ST-Elevation Myocardial Infarction: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines developed in collaboration with the American Academy of Family Physicians, Society for Cardiovascular Angiography and Interventions, and the Society of Thoracic Surgeons. J Am Coll Cardiol 2011; 57: e215-e367 [PMID: 21545940 DOI: 10.1016/j.jacc.2011.02.011]

3. Roger VL, Go AS, Lloyd-Jones DM, Adams RJ, Berry JD, Brown TM, Carnethon MR, Dai S, de Simone G, Ford ES, Fox CS, Fullerton HJ, Gillespie C, Greenlund KJ, Hailpern SM, Heit JA, Ho PM, Howard VJ, Kissela BM, Kittner SJ, Lackland DT, Lichtman JH, Lisabeth LD, Makuc DM, Marcus GM, Marelli A, Matchar DB, McDermott MM, Meigs JB, Moy CS, Mozaffarian D, Mussolino ME, Nichol G, Paynter NP, Rosamond WD, Sorlie PD, Stafford RS, Turan TN, Turner MB, Wong ND, Wylie-Rosett J. Heart disease and stroke statistics--2011 update: a report from the American Heart Association. Circulation 2011; 123: e18-e209 [PMID: 21160056 DOI: 10.1161/CIR.0b013e3182009701]

4. Fox KA, Birkhead J, Wilcox R, Knight C, Barth J. British Cardiac Society Working Group. British Cardiac Society Working Group on the definition of myocardial infarction. Heart 2004; 90:603-609 [PMID: 15145852]

5. Fox KA, Steg PG, Eagle KA, Goodman SG, Anderson FA, Granger CB, Flather MD, Budaj A, Quill A, Gore JM. Decline in rates of death and heart failure in acute coronary syndromes, 1999-2006. JAMA 2007; 297: 1892-1900 [PMID: 17473299 DOI: 10.1001/jama.297.17.1892]

6. Brieger DB, Redfern J. Contemporary themes in acute coronary syndrome management: from acute illness to secondary prevention. Med J Aust 2013; 199: 174-178 [PMID: 23909538 DOI: 10.5694/mja12.11224]

7. Nawar EW, Niska RW, Xu J. National Hospital Ambulatory Medical Care Survey: 2005 emergency department summary. Adv Data 2007; (386): 1-32 [PMID: 17703794]

8. Fox KA, Carruthers KF, Dunbar DR, Graham C, Manning JR, De Raedt H, Buyschaert I, Lambrecht D, Van der Werf F. Underestimated and under-recognized: the late consequences of acute coronary syndromes, 1999-2006. JAMA 2007; 297: 1745-1754 [PMID: 17473299 DOI: 10.1001/jama.297.17.1892]

9. Reimer KA, Lowe JE, Rasmussen MM, Jennings RB. The wavefront phenomenon of ischemic cell death. 1. Myocardial infarct size vs duration of coronary occlusion in dogs. Eur Heart J 2010; 31: 759-774 [PMID: 2080510] DOI: 10.1093/eurheartj/ehq326]

10. Ahmed N, Carrick D, Layland J, Oldroyd KG, Berry C. The role of cardiac magnetic resonance imaging (MRI) in acute myocardial infarction (AMI). Heart 2007; 93: 860-865 [PMID: 17889838]

11. Raj V, Agrawal SK. Ischaemic heart disease assessment by cardiovascular magnetic resonance imaging. Postgrad Med J 2010; 86: 532-540 [PMID: 20841330 DOI: 10.1136/pmj.2009.093856]

12. Schwitter J, Arai AE. Assessment of cardiac ischaemia and viability: role of cardiovascular magnetic resonance. Eur Heart J 2011; 32: 799-809 [PMID: 21396845 DOI: 10.1093/eurheartj/eth481]

13. Gersh BJ. Noninvasive imaging in acute coronary disease. A clinical perspective. Circulation 1991; 84: 1140-1147 [PMID: 1832098]

14. Gani F, Jain D, Lahiri A. The role of cardiovascular imaging techniques in the assessment of patients with acute chest pain. Nucl Med Commun 2007; 28: 441-449 [PMID: 17460534 DOI: 10.1097/NMN.0b013e3287449b11]

15. Gruettner J, Henzler T, Suesbeck T, Fink C, Borggreve M, Walter T. Clinical assessment of chest pain and guidelines for imaging. Eur J Radiol 2012; 81: 3663-3668 [PMID: 21396792 DOI: 10.1016/j.ejrad.2011.06.031]

16. Rathore SS, Curtis JP, Chen J, Wang Y, Nallamothu BK, Ep-
stein AJ, Krumholz HM. Association of door-to-balloon time and mortality in patients admitted to hospital with ST elevation myocardial infarction: national cohort study. BMJ 2009; 338: b1807 [PMID: 19454739 DOI: 10.1136/bmj.b1807]

17 Kushner FG, Hand M, Smith SC, King SB, Anderson JL, Antman EM, Bailey SR, Bates ER, Blankenship JC, Casey DE, Green LA, Hochman JS, Jacobs AK, Krumholz HM, Morrison DA, Ornato JP, Pearle DL, Peterson ED, Sloan MA, Whitlow PL, Williams DO. 2009 Focused Updates: ACC/AHA Guidelines for the Management of Patients With ST-Elevation Myocardial Infarction ( updating the 2004 Guideline and 2007 Focused Update) and ACC/AHA/SCAI Guidelines on Percutaneous Coronary Intervention ( updating the 2005 Guideline and 2007 Focused Update): a report of the American College of Cardiology Foundation/ American Heart Association Task Force on Practice Guidelines. Circulation 2009; 120: 2271-2306 [PMID: 19923169 DOI: 10.1161/CIRCULATIONAHA.109.192663]

18 Camici P, Ferrannini E, Opie LH. Myocardial metabolism in ischemic heart disease: basic principles and application to imaging by positron emission tomography. Prog Cardiovasc Dis 1989; 32: 217-238 [PMID: 2682779 DOI: 10.1016/0033-0620(89)90027-3]

19 Camici PG, Rimoldi OE. Myocardial blood flow in patients with hypertaining myocardia. Cardiovasc Res 2003; 57: 302-311 [PMID: 12566103 DOI: 10.1016/s0008-6363(02)00716-2]

20 Bonow RO, Maurer G, Lee KL, Holly TA, Binkley PF, Desvigne-Nickens P, Drozdz J, Farsky PS, Feldman AM, Doestl T, Michler RE, Berman DS, Nicolau JC, Pellicka PA, Wrobel K, Alotti N, Asch FM, Favaloro LE, She L, Velazquez Ej, Jones RH, Panza JA. Myocardial viability and survival in ischemic left ventricular dysfunction. N Engl J Med 2011; 364: 1617-1625 [PMID: 21463153 DOI: 10.1056/NEJMoa1100358]

21 Galizio L, Paraggio L, De Caterina AR, Fedele E, Locorotondo G, Leccisotti L, Giordano A, Rebuzzi AG, Crea F. Positron emission tomography in acute coronary syndromes. J Cardiovasc Trans Res 2012; 5: 11-21 [PMID: 22170257 DOI: 10.1080/s12265-011-0932-9]

22 Miller JM, Rochitte CE, Dewey M, Arbab-Zadeh A, Niinuma H, Gottlieb I, Paul N, Clouse ME, Shapiro EP, Hoe J, Lardo AC, Bush DE, De Roos A, Cox C, Brinker J, Lima JA. Diagnostic performance of coronary angiography by 64-row CT. N Engl J Med 2008; 359: 2352-2363 [PMID: 19038879 DOI: 10.1056/NEJMoa0805777]

23 Stein F, Vankoubek AY, Matta F, Sostman HD. 64-slice CT for diagnosis of coronary artery disease: a systematic review. Am J Med 2008; 121: 715-725 [PMID: 18691486 DOI: 10.1016/ ja.ajmed.2008.02.039]

24 Litt HJ, Gatsonis C, Snyder B, Singh H, Miller CD, Entrikin J, Leaming JM, Gavin LJ, Pacella CB, Hollander JE. CT angiography for safe discharge of patients with possible acute coronary syndromes. N Engl J Med 2012; 366: 1393-1403 [PMID: 2249295 DOI: 10.1056/NEJMoai201163]

25 Goldstein JA, Chinainay KM, Abidov A, Achenbach S, Berman DS, Hayes SW, Hoffmann U, Lesser JR, Mikati IA, O'Neill BJ, Shaw LJ, Shen MY, Valeti US, Raff GL. The CT-STAT (Coronary Computed Tomographic Angiography for Systematic Triage of Acute Chest Pain Patients to Treatment) trial. J Am Coll Cardiol 2011; 58: 1414-1422 [PMID: 21939822 DOI: 10.1016/j.jacc.2011.03.068]

26 Hoffmann U, Truong QA, Schoenhoff DA, Chau ET, Wooldar PK, Nagurney JT, Pope JH, Hauser TH, White CS, Weiner SG, Kalanjan A, Collins M, Liang PI, Peacock WF, Zakrovsy P, Hayden D, Goehler A, Lee H, Gazelle GS, Wiviott SD, Fleg JL, Udelson JE. Coronary CT angiography versus standard evaluation in acute chest pain. N Engl J Med 2012; 367: 299-308 [PMID: 22830462 DOI: 10.1056/NEJ Moai2011611]

27 Taylor AJ, Cerqueira M, Hodgson JM, Mark D, Min J, O'Gara P, Rubin GD, Kramer CM, Berman D, Brown A, Chaudhry FA, Curey RC, Desai MY, Einstein AJ, Gomes AS, Harrington R, Hoffmann U, Khare R, Lesser J, McGann C, Rosenberg A, Schwartz R, Shelton M, Smetana GW, Smith SC, ACCF/SCCT/AHA/ASE/ASNC/SCAI/SCMR 2010 appropriate use criteria for cardiac computed tomography. A report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force, the Society of Cardiovascular Computed Tomography, the American College of Radiology, the American Heart Association, the American Society of Echocardiography, the American Society of Nuclear Cardiology, the North American Society for Cardiovascular Imaging, the Society for Cardiovascular Angiography and Interventions, and the Society for Cardiovascular Magnetic Resonance. J Am Coll Cardiol 2010; 56: 1864-1894 [PMID: 21087721 DOI: 10.1016/j.jacc.2010.07.005]

28 Budoff MJ, Achenbach S, Blumenthal RS, Carr JJ, Goldin JG, Greenland P, Guerci AD, Lima JA, Rader DJ, Rubin GD, Shaw LJ, Wiegers SE. Assessment of coronary artery disease by cardiac computed tomography: a scientific statement from the American Heart Association Committee on Cardiovascular Imaging and Intervention, Council on Cardiovascular Radiology and Intervention, Committee on Cardiac Imaging, Council on Clinical Cardiology. Circulation 2006; 114: 1761-1791 [PMID: 17105792 DOI: 10.1161/CIRCUL ATIONAHA.106.178458]

29 Hamon M, Morello R, Riddell JW, Hamon M. Coronary arteries: diagnostic performance of 16- versus 64-section spiral CT compared with invasive coronary angiography—meta-analysis. Radiology 2007; 245: 720-731 [PMID: 17951354]

30 Vanhoenacker PK, Heijenbrok-Kal MH, Van Heste R, Decramer I, Van Hoe LR, Wijns W, Hunink MG. Diagnostic performance of multidetector CT angiography for coronary artery disease: meta-analysis. Radiology 2007; 244: 419-428 [PMID: 17641365 DOI: 10.1148/radiol.24206218]

31 Almoudi M, Sun ZH. A head-to-head comparison of the coronary calcium score by computed tomography with myocardial perfusion imaging in predicting coronary artery disease. J Geriatr Cardiol 2012; 9: 349-354 [PMID: 23341839 DOI: 10.3724/SPJ.1263.2012.06291]

32 Patel AR, Bhave NM, Mor-Avi V. Myocardial perfusion imaging with cardiac computed tomography: state of the art. J Cardiovasc Trans Res 2013; 6: 695-707 [PMID: 23963959 DOI: 10.1080/s12265-013-9499-3]

33 Coelho-Filho OR, Rickers C, Kwong RW, Jerosch-Herold M. MR myocardial perfusion imaging. Radiology 2013; 266: 701-715 [PMID: 23431226 DOI: 10.1148/radiol.12110918]

34 Becker A, Becker C. CT imaging of myocardial perfusion: possibilities and perspectives. J Nucl Cardiol 2013; 20: 289-296 [PMID: 23479267 DOI: 10.1007/s12350-013-9681-7]

35 Gould KL, Lipscomb K. Effects of coronary stenoses on coronary flow reserve and resistance. Am J Cardiol 1974; 34: 48-55 [PMID: 4835753]

36 Siemers PT, Higgins CB, Schmidt W, Ashburn W, Hagan P. Detection, quantitation and contrast enhancement of myocardial infarction utilizing computerized axial tomography: a preliminary report. Radiology 1978: 13; 103-109 [PMID: 77854]

37 Hoffmann U, Milia A, Enzweiler C, Ferencik M, Gulick S, Titus J, Achenbach S, Kwaist D, Sovovnik D, Brady TJ. Acute myocardial infarction: contrast-enhanced multi-detector row CT in a porcine model. Radiology 2004; 231: 697-701 [PMID: 15118118 DOI: 10.1148/radiol.2313030132]

38 Nikolaou K, Sanz J, Poon M, Wintersperger BJ, Ohnesorge B, Rius T, Fayad ZA, Reiser MF, Becker CR. Assessment of myocardial perfusion and viability from routine contrast-enhanced 16-detector-row computed tomography of the heart: preliminary results. Eur Radiol 2005; 15: 864-871 [PMID: 15776243 DOI: 10.1007/s00330-005-2672-6]
pervasive use of 320-detector computed tomography (CT) has revolutionized the field of cardiac imaging. CT coronary angiography (CTCA) is now a widely accepted method for the detection of coronary artery disease (CAD) and has been shown to be non-inferior to traditional invasive angiography in many studies. However, the role of CTCA in patients with chest pain is still evolving.

One of the main advantages of CTCA is its ability to detect calcified plaques, which are highly predictive of future cardiovascular events. CTCA also provides excellent anatomic detail of the coronary arteries, allowing for accurate assessment of stenosis severity. This is particularly useful in high-risk patients such as those with diabetes or renal insufficiency, who may not be good candidates for conventional invasive angiography.

CTCA can also be used to assess myocardial perfusion, providing valuable information about the distribution of blood flow to the myocardium. This is particularly useful in patients with chest pain, as it can help to identify regions of ischemia that may not be apparent on traditional stress imaging.

Furthermore, CTCA can be used to assess myocardial viability, which is important for guiding revascularization strategies. Patients with severe ischemia and viable myocardium may benefit from percutaneous revascularization, while those with non-viable myocardium may require medical therapy alone.

Despite these advantages, CTCA has limitations. It is not always able to detect non-calcified plaques, which can be problematic in low-risk patients. Additionally, CTCA may be less sensitive than invasive angiography in assessing the severity of stenosis in small vessels.

In conclusion, CTCA has a growing role in the assessment of chest pain patients. It provides valuable information about the coronary arteries and myocardium, and can help to guide patient management. However, it is important for clinicians to be familiar with the strengths and limitations of CTCA in order to use it effectively in clinical practice.
Nanking D, Kneifel S, Bertschinger K, Büchi M, 2009; Azarisman SM et al. CMR role in assessing ACS
