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Comparative assessment of non-invasive imaging in detecting coronary artery disease

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Abstract

Coronary artery disease (CAD) has an important impact on the morbidity and mortality in the West and health service resources worldwide. It is therefore crucial to accurately diagnose CAD early, in an attempt to limit its burden on patients and society, potentially by optimum risk stratification, accurate diagnosis and management. Invasive coronary angiography (ICA) is the conventional gold standard imaging investigation for the coronary circulation and assessment of disease severity. However, it is an invasive procedure and is associated with risks, although rare. In addition, it detects luminal stenosis but not the functional importance of those anatomical lesions. Therefore, a wide variety of non-invasive imaging developed to evaluate the presence and severity of CAD, including anatomical techniques e.g. coronary CT that assesses coronary stenosis, and quantifies coronary calcium, hence the burden of atherosclerotic plaques and functional imaging e.g. stress echocardiography, nuclear imaging by SPECT and PET and stress CMR. Selection of the most appropriate imaging, therefore, is challenging and requires knowledge of patients' pre-test probability and prevalence of disease, their advantages and limitations, cost and availability. This review attempts to provide an overview of the current supporting evidence of the role of non-invasive imaging in diagnosing CAD, in addition to its prognostic value, limitations and advantages.

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Introduction

Coronary artery disease (CAD) is the most prevalent and the leading cause of morbidity and mortality worldwide, particularly in the West.[1] 6% of visits to emergency departments and 27% of emergency hospital admissions are related to chest pain.[2] In the UK, one in five men and one in six women dies from CAD. This is in addition to an annual financial cost of 9 billion sterling pounds spent on atherosclerosis disease, let alone the impaired individual's productivity.[3] Coronary atherosclerosis might be asymptomatic or present with chest pain or discomfort during exertion (stable angina).[4] More seriously, it might present with acute myocardial infarction (MI) or stroke, as a result of rupture of vulnerable atheroma causing arterial thrombosis.[4]

In view of the above, it is crucial to accurately diagnose CAD as early as possible in an attempt to limit its burden on patients and society. Invasive coronary angiography (ICA) is the modality of choice to assess coronary artery stenosis. Since it was performed for the first time in 1958 by F. Mason Sones in Ohio, [5] ICA has remained the "gold standard" investigation to confirm the presence of CAD.[5, 6] However, it is an invasive procedure and is associated with potential serious risks and complications.[5] Major complications, although rare, include death, stroke, coronary artery dissection and arterial access complications.[7] In addition, it is a costly procedure and includes radiation exposure. For these reasons, non-invasive imaging tests have emerged as alternatives or as gatekeepers to reduce the number of unnecessary diagnostic interventions. Many non-invasive techniques are available for assessment of patients with suspected CAD, making the choice of the most appropriate one in the light of the pre-test probability for CAD, an important pre-requisite. In addition, each imaging modality has its own advantages and limitations, including availability and cost implications.

This review focuses on the currently supporting evidence of diagnostic accuracy of anatomical (Computed tomography coronary angiography (CTCA) and magnetic resonance angiography (MRA)) and functional (nuclear imaging; includes single-photon emission computed tomography (SPECT) and positron emission tomography (PET), Stress echocardiography and Stress cardiac magnetic resonance (CMR)) in detecting CAD, as well as the comparative assessment of each.

Stress Echocardiography

Stress echocardiography is a widely used non-invasive imaging modality in clinical practice. It has an important role in evaluating CAD; it is used to detect the presence and the extent of ischaemia, to provide prognostic information, to assess LV function and identify myocardial viability, hence assists in most management approach.[8,9] In clinical practice, two-dimensional (2-D) transthoracic echocardiography is the most commonly used technique to evaluate myocardial ischaemia.

In order to detect myocardial ischaemia, images at rest and during or immediately after stress (physical exercise or pharmacological stress) are compared. Regional segmental dysfunction are taken as signs of ischaemia and are detected by observing wall motion abnormalities which develop or worsen with stress and disappear at rest. Dobutamine is mainly used in clinical practice as a good stressor, alternative to exercise; it increases heart rate and myocardial contractile function like physical exercise.[8,9] The standard dobutamine stress protocol includes intravenous infusion of dobutamine at 5mcg/kg/min, increased to 10, 20, 30, and 40 mcg/kg/min (over 3-minutes period). In case the maximum heart rate is not achieved, atropine is administered.[10] Other pharmacological stressors include vasodilators (dipyridamole and adenosine), which pool blood from the area supplied by the stenosed artery.[8]

Contrast echocardiography has been introduced to solve the problem of unclear endocardial border delineation. The contrast material consists of "microbubbles" of an inert gas that diffuse in blood and enhance ECHO signal. It is also used to assess myocardial perfusion.[11,12] Further technologies that aim to overcome the qualitative assessment of stress ECHO are real-time 3-D ECHO, strain imaging that measures myocardial velocity and deformation and measurement of coronary flow reserve (CFR) by Doppler.

Two-dimensional (2-D) transthoracic stress echocardiography
The most recent meta-analysis by Picano et al (2008),[13] of 5 studies (435 patients); showed that both dobutamine and dipyridamole have comparable sensitivity, specificity and diagnostic accuracy; (86% vs. 85%), (86% vs. 89%), and (84% vs. 87%), respectively. This is in agreement with previous meta-analysis conducted by Picano in 2000,[14] in which the diagnostic accuracy of the two stressors was comparable, dobutamine 80% and dipyridamole 77%. However, dobutamine showed higher sensitivity (77% vs. 71%, $p<0.05$) but lower specificity (87% vs. 93%, $p<0.05$) compared to dipyridamole. Another meta-analysis by Kim et al (2001)[15] showed higher sensitivity with dobutamine; 80% compared to dipyridamole; 70% and adenosine; 72% and lower specificity; 84% compared to 93% and 91%, respectively. It has been shown that dipyridamole and adenosine have higher specificities when used with ECHO and higher sensitivities when used with SPECT; 89% and 90%, respectively.

Dipyridamole has also been shown to have comparable diagnostic accuracy to exercise echocardiography. This was demonstrated by de Albuquerque Fonseca et al meta-analysis (2001)[16] in which 8 studies were included involving 533 patients with suspected CAD. Sensitivity, specificity and diagnostic accuracy of exercise stress and dipyridamole echocardiography were 79% vs. 72% ($p<0.05$), 82 % vs. 92 % ($p<0.05$) and 80% vs. 77% (NS), respectively. A meta-analysis by Noguchi et al (2005)[17] showed that the mean sensitivity and specificity of exercise echocardiography were: 82.6% and 84.4%, dobutamine: 79.6% and 85.1%, adenosine: 68.4% and 80.9%, dipyridamole: 71.0% and 92.2%, transatrial pacing transesophageal echocardiography (Tap-TEE): 86.2% and 91.3, and transatrial pacing transthoracic echocardiography (Tap-TTE): 90.7% and 86.1%. They concluded that Tap-TEE was very accurate in excluding CAD but, on the expense of its limitation, being an invasive investigation. In general, exercise test is considered satisfactory in diagnosing CAD and Dobutamine a good alternative. Adenosine is the least used stressor in diagnosing CAD.

Dobutamine stress echocardiography (DSE)

An analysis by Geleijnse et al (1997)[18] of 28 studies involving 2,246 patients, reported DSE as having better diagnostic accuracy than exercise or dipyridamole echocardiography, hence is considered a good alternative to exercise stress test. DSE showed an overall sensitivity of 80%, specificity of 84% and diagnostic accuracy of 81% in diagnosing CAD. In single-vessel, two-vessel or three-vessel disease, DSE had a mean sensitivity of 74%, 86% and 92%, respectively. In comparison with other non-invasive stress tests, DSE showed comparable diagnostic accuracy to radionuclide perfusion imaging (dobutamine technetium 99m (Tc-99m)). Sensitivity, specificity and accuracy were 76% vs. 81%, 85% vs. 71% (p<0.01) and 80% vs.78%, respectively. In comparison with radionuclide perfusion imaging, DSE has been shown to be more specific and less sensitive in detecting CAD.

Contrast echocardiography

A meta-analysis by Abdelmoneim et al (2009),[19] demonstrated the role of quantitative myocardial contrast echocardiography (MCE) in the diagnosis of CAD by measuring of perfusion parameters (A, β and Aβ). A recent meta-analysis by de Jong MC et al (2012)[20] involving 795 patients demonstrated that perfusion ECHO has an overall sensitivity of 87% and a specificity of 72% with similar diagnostic performance compared to SPECT.

Strain Imaging

A study by Jamal et al (2002),[21] showed that Doppler longitudinal systolic strain and strain rates were found to be sensitive in identifying and quantifying regional myocardial ischaemia. Other studies by Liang HY (2006)[22] and Choi et al (2009)[23] demonstrated the role of 2D- speckle strain in identifying myocardial ischaemia.

Coronary flow reserve

A study by Kataoka Y et al (2007)[24] involving 100 patients demonstrated that measuring CFR identifies the presence of CAD with a sensitivity of 85%, specificity of 81%, positive predictive value (PPV) of 89%, and negative predictive value (NPP) of 93%. This result was confirmed by recent study by Haraldsson et al (2014)[25]. Also, a recent prospective study conducted by Cortigiani et al (2012)[26] demonstrated the prognostic value of CFR.

3-D Echocardiography

Ahmad et al (2001),[27] assessed the feasibility of using real-time three-dimensional echocardiography (RT-3D) during dobutamine stress with a sensitivity of 87.9% compared to 79.3% for 2D echocardiography. Another study by Badano et al (2010)[28] showed comparable diagnostic accuracy with sensitivity of 80% vs. 78% and specificity of 87% vs. 91% for 3D and 2D echocardiography, respectively.

Prognostic value of stress echocardiography

A recent study conducted by Yao et al (2012)[29] demonstrated that patients with normal stress test (exercise or dobutamine ECHO) carried good prognosis with low risk for having future cardiac events. These results are in accordance with previous studies conducted by Marwick et al, 2001,[30] Sicari et al, 2003[31] and Yao et al, 2003.[32]

Limitation and advantages

The main limitations of echocardiography include; interpretation subjectivity i.e. it depends on sonographer skills and experience, modest image quality in patients with obstructive lung disease, obesity or those with chest deformities. However, these issues can be minimised by contrast.[8] The main advantages include; safety with no radiation or ionizing substances, wide availability and feasibility at low cost.[8]

Nuclear Imaging (Spect and Pet)

Nuclear imaging is a well-established non-invasive technique used to detect significant CAD. The basic concept in nuclear cardiology is detecting areas of myocardium where perfusion is reduced; this is achieved by using a radioactive tracer which in turn generates a signal that is received by SPECT or PET cameras, preferably after stress, to detect inducible ischaemia.[6] The two main tracers used in SPECT are Thallium-201 (Tl-201) and technetium-99 (99mTc either sestamibi or tetrofosmin); the latter is used more frequently with lesser tissue attenuation and lower radiation dose.[33] For PET, the most commonly used tracers are Rubidium-82 (Rb-82), N-13 ammonia, and recently[18] Fluorodeoxyglucose (18-FDG) which is a metabolic tracer used to image atherosclerotic plaque. [6]

Generally, patients with intermediate to high pre-test probability for CAD are good candidates, those who are unable to exercise or have resting ECG abnormalities are considered as class I indication for SPECT according to ESC guideline. SPECT is indicated as first line investigation.[8] Also it has a role in diagnosing ACS; it has been shown that normal perfusion study at the time of chest pain rules out ACS and normal study at rest excludes ACS thus, reducing unnecessary hospitalizations.[34]

Single-Photon Emission Computed Tomography (SPECT) Fleishmann et al (1998),[35] meta-analysis of 44 articles using Tl 201 or Tc 99m sestamibi demonstrated that both exercise echocardiography and exercise SPECT had similar sensitivities; 85% vs. 87%, respectively but with lower specificity compared to echocardiography; 64 vs. 77%. This result is in agreement with Kim et al (2001) 15 meta-analysis, in which using dobutamine with SPECT and ECHO showed similar sensitivities, 82% and 80%, respectively. Specificity was 75% for SPECT which was lower than 84% for ECHO. Another meta-analysis by Quiñones et al [36] showed that exercise SPECT with Tl-201 has comparable diagnostic accuracy to exercise echocardiography. Furthermore, a meta-analysis by Imran et al[37] showed that stress SPECT (using exercise in three studies, dobutamine in one study and dipyridamole in 6 studies) had higher sensitivity (88% vs. 70%) and lower specificity (67% vs. 90%) compared to ECHO.

Positron Emission Tomography (PET)

A meta-analysis by Nandalur et al (2008)[38] of 19 studies (1442 patients) demonstrated that PET had a sensitivity of 92% and a specificity of 85% in diagnosing CAD, depending on the territory supplied by individual coronary artery. A recent meta-analysis by Parker et al (2012)[39] showed that PET has higher sensitivity compared to SPECT; 92.6% vs. 88.3% (p=0.035), but whereas specificities were not different; 81.3% vs. 75.8%, respectively. Another meta-analysis by Al Moudi et al (2011)[40] showed a sensitivity, specificity and diagnostic accuracy of 91% vs. 82%, 89% vs. 76% and 89% vs. 83% for PET vs. SPECT, respectively. A study conducted by Bateman et al,[41] showed that ECG-gated perfusion imaging by PET had similar sensitivity to ECG-gated technetium-99m sestamibi SPECT; 86% vs. 81% and 87% vs. 82% for PET vs. SPECT at 50% and 70% stenosis threshold, respectively, Whereas specificity was higher in PET than SPECT; 100% vs. 66% and 93% vs. 73%, respectively. Moreover, a recent meta-analysis conducted by Jaarsma et al, 2012[42] showed a sensitivity of 84% vs. 88% and a specificity of 81 % vs. 61% for PET and SPECT, respectively. PET showed higher specificity than SPECT and hence higher diagnostic performance.

Prognostic value of myocardial perfusion

For SPECT a review by Shaw et al (2004)[43] demonstrated that the annual rate of death and non-fatal MI were 0.6% and 5.9% per year with normal and abnormal perfusions scans, respectively. For PET, Marwick et al (1997)[44] demonstrated how free survival from heart events decreased from 90% with normal scan to 87% and 75% in patients with mild and moderate to severe scan result, respectively. This result is in line with another study by Yoshinga et al (2006).[45]

Limitation and advantages

The main limitation of nuclear imaging includes radiation exposure. SPECT is associated with soft tissue attenuation artefacts and is expensive compared to echocardiography. However, it is less expensive and more available compared to PET. The main advantages of nuclear imaging include high sensitivity associated with technical success rate (less operator-dependent). PET has been associated with better image quality and has the ability to quantify blood flow.[8, 46]

Cardiac Magnetic Resonance (CMR)

Stress cardiac magnetic resonance (CMR) is a non-invasive, x-ray free imaging modality which has developed over the past decade to become an essential investigation tool in the assessment of patients with heart disease in general and coronary artery disease in particular.[46] CMR is primarily a functional test; however it has the ability to identify the anatomy of coronary arteries. Detection of myocardial ischaemia is mainly achieved by 2 main techniques; assessment of wall motion abnormalities mainly with dobutamine and[8] assessment of myocardial perfusion during vasodilators (adenosine and dipyridamole) infusion. Contrast agent "gadolinium- based contrast agents" or (GBCAs) is used for this purpose.[8, 46] CMR is mainly indicated for patients with intermediate pre-test likelihood of CAD who do not have the ability to exercise.[47] Also, it has a role in the emergency department[49, 48] and it has a potential ability to differentiate ACS from other non-coronary causes of acute chest pain.[50-52]

Nandalur et al meta-analysis (2007)[53] showed that both wall motion and perfusion CMR had good sensitivity and specificity with relatively high sensitivity associated with stress perfusion CMR. Sensitivity vs. specificity were 83% vs. 86% and 91% vs. 81%, respectively. This result is in line with a recent meta-analysis by Hamon et al (2010)[54] of 35 studies (2472 patients) demonstrated that stress perfusion CMR imaging is highly sensitive and moderately specific in diagnosing CAD; with overall sensitivity and specificity of 89% and 80%, respectively. Furthermore, a large prospective randomised controlled trial (CE-MARC), 2012[55] involving 628 patients with 39% prevalence of coronary heart disease (represents a real world population) showed that multiparametric CMR had sensitivity, specificity, PPV and NPV of 86.5%, 83.4%, 77.2% and 90.5%, respectively. For SPECT lower sensitivity was observed; 66.5% with no difference in specificity 82.6%; PPV and NPV were 71.4% and 79.1%, respectively. Another recent large multicenter trial (MR-IMPACT II), 2013[56] showed that perfusion CMR had a higher sensitivity 67% vs. 59% and lower specificity 61% vs. 72% compared to SPECT. This is in agreement with (MR-IMPACT I),[57] which demonstrated a higher sensitivity 85% vs. 60% and lower specificity 67% vs. 75% compared to SPECT. CMR has been recommended as being safe, having demonstrated no severe adverse events[58] and requiring no ionizing radiation, unlike SPECT.[59]

Compared to other non-invasive perfusion imaging, de Jong et al, 20 demonstrated that CMR is superior to perfusion ECHO and SPECT with sensitivity of 91% vs. 87% and 83% and specificity of 80% vs.72% and 77%, respectively. Another meta-analysis by Jaarsma et al., 2012[42] showed high sensitivities (CMR; 89%, SPECT; 88%, and PET; 84%), specificity was 76% which is comparable to PET (81%) and higher than SPECT (61%).

Prognostic value of CMR

A meta-analysis by Lipinski et al (2013)[60] found that the annual cardiovascular death rate or MI were 2.8 vs. 0.3% ($p<0.0001$) and 2.6% vs. 0.4% ($p<0.0005$) for positive study versus negative study, respectively. In addition, a study by Korosoglou et al (2010)[61] demonstrated that using a standard high dose dobutamine CMR showed a very low risk for cardiac death or MI during a follow-up period of 2±1 year.

Limitation and advantages

The main limitations of CMR include; high cost, long study time, availability of specialised expertise, patient claustrophobia, pacemakers and cardioverter defibrillators are absolute contraindications to CMR scanning in addition to other implanted medical devices[4,46,62,63] and gadolinium- associated nephrotic systemic fibrosis[64] although it is rare.[65] The main advantages of CMR include; lack of radiation and its ability to assess cardiac structure and function concurrently.

Computed Tomography Angiography (CTA)

Computed tomography angiography (CTA) is a non-invasive imaging test used to assess the presence of coronary artery stenosis. CTA is similar to ICA in identifying the anatomy of coronary artery tree by using iodinated contrast agent and X ray imaging. 8 Currently, 64-detector CTA represents "state of the art" for coronary artery imaging; 256 and 320 MDCT have been developed to improve image quality.[8] CTA is indicated mainly for symptomatic patients with intermediate risk of CAD including those with equivocal stress test.[63] Also, CTA is indicated to assess acute chest pain at emergency.[47] It has high diagnostic accuracy according to a number of early and recent studies; Gallagher et al[66], Goldstein et al,[67] ROMICAT trial, 2009[68] and (ROMICAT-II), 2012[69]. Coronary artery calcium (CAC) can be quantified by CTA using the Agatston Score.[8] It has been shown that high calcium score is related to the presence of atherosclerotic plaque and significant CAD.[70-72]

A meta-analysis by Hamon et al (2007)[73] comparing 16 and 64-section CTs showed that both techniques had high sensitivity (95% vs. 97%) and high NPV (92% vs. 96%), respectively. Another meta-analysis by Abdulla et al (2007)[74] showed that CTA sensitivities and specificities were 97.5% (96-99) and 91% (87.5-94), PPV and NPV were 93% and 96.5%, respectively. It has been concluded that 64-slice angiography (64-SCTA) has a high diagnostic accuracy and it might be a competent alternative to invasive coronary angiography. These results are comparable with that of Mowatt et al (2008)[75] which showed sensitivities and specificities of 99% and 89%, median PPV and NPV of 93 %(64-100%) and 100 %(86%-100%), respectively. Furthermore, the ACCURACY (2008) study[76] evaluated ECG-gated 64 MDCT and demonstrated comparable results with angiography; sensitivity (95% and 94%), specificity; (83% and 83%), PPV; (64% and 48%), NPV; (99% and 99%) for 50% and 70% stenosis, respectively. This result is in accordance with that of Meijboom et al (2008).[77] The more recent multicentre study is CORE-64 (2012)[78], which suggested that CCTA is suitable for patients with low to intermediate pre-test probability who had mild CAC.

For 320- detector CTA, A recent meta-analysis by Gaudio et al (2013)[79] showed a pooled sensitivity of 95.4%, specificity of 94.7%, PPV of 94.4% and NPV of 94.5%. The result of this meta-analysis is matching another recent meta-analysis by Li et al (2013).[80] Comparing multidetector CCTA with other non-invasive imaging techniques, a meta-analysis by Schuijf et al (2006)[81] showed that MSCT (4, 8 and 16-detectors) has higher diagnostic accuracy compared to CMR with sensitivity of 85% vs. 72% and specificity of 95% vs. 87%, respectively. Moreover, a recent single centre trial by Chen et al (2014)[82] showed comparable results; sensitivity; 93% vs. 98%, specificity; 96% vs. 96%, PPV; 91% vs. 91% and NPV; 97% vs. 99% for CMR and 320-detector CTA, respectively. Furthermore, a number of small studies compared MSCT with stress nuclear imaging have shown that MSCT has higher diagnostic accuracy.[83-85]

CT perfusion imaging is a new promising technology that aims to enhance the role of CTA in practice by allowing it to detect coronary stenoses and its functional significance in single test. A meta-analysis by Tashakkor et al (2012)[86] showed that CT perfusion combined to CTCA had a sensitivity of 81%, specificity of 93%, PPV 87% and NPV 88%. Moreover, a prospective multicentre international trial (CORE 320)[87, 88] showed that combining CTA and CT perfusion had a strong diagnostic accuracy in determining flow-limiting coronary stenoses as compared to ICA and SPECT-MPI.

Prognostic value of MSCT

In the intermediate term follow up, meta-analyses by Abdulla et al (2011)[89] and Hulten et al (2011)[90] have shown that normal CTA study is associated with excellent prognosis and rare cardiac events. These results are in line with that of Andreini et al (2012)[91] which confirms the long-term prognostic role of CTA in assessment of CAD.

Limitation and advantages:

The main limitations of CTA include; exposure to ionizing radiation, use of iodinated contrast, not suitable for patients with atrial fibrillation or fast heart rate, need of long breath hold, coronary calcification affects the diagnostic accuracy of CTA, and anatomic modality. In addition, CTA does not have the ability to assess the haemodynamic significance of coronary stenosis which might improve with the use of perfusion CT. The main advantages of MSCT include; high diagnostic accuracy with high sensitivity and NPV, impressive image quality and its ability to assess atheromatous plague at early stage.[8,46]

Combined Technology

Combined technology is a new emerging approach to non-invasively evaluation of patients with suspected CAD. It includes integration of techniques that assess anatomy, CTA, with those assessing physiological significance of coronary atherosclerosis, namely, SPECT and PET.[92] The aim, then, is to improve the diagnostic performance of tests by dual-modality approach which can lead to more accurate decision making regarding further invasive assessment and interventional management.[93]

PET/CT and SPECT/CT

Di Carli et al (2007)[94] demonstrated how PET/CT provides complementary information; Sampson et al[95] demonstrated high sensitivity (93%) and diagnostic accuracy (87%) associated with PET/CT. Al-Moudi et al meta-analysis (2011) 40 have shown a moderate diagnostic accuracy (sensitivity; 85%, specificity; 83%, and accuracy 88%) compared to PET alone. Furthermore, using PET with FDG or fluorine 18 (FDG PET/CT) can be used for risk assessment of patients with suspected CAD by identifying inflammation and high risk vulnerable plaque.[96] Also, Santana et al (2009)[97] in a small study involving 50 patients demonstrated how MPI (SPECT &PET)/CT has higher diagnostic performance compared to either techniques alone. This result is in agreement with data Gaemperli et al (2011).[98]

CMR/CT

In a recent prospective trial (MARCC study), 2013,[99] demonstrated that using combined CMR/CT resulted in an increase in the specificity and overall diagnostic accuracy, 94% and 91%, respectively compared with CMR alone; 82% and 83%, respectively ($p=0.016$) and CT alone; 39% and 57%, respectively ($p<0.0001$).

PET/MR

The validity of this recent modality of cardiac hybrid imaging has not been assessed, particularly against PET/CT. However, such technique can provide multimodality assessment by MR and functional assessment (perfusion) by PET with the advantage of lacking ionizing radiation.[100]

Hybrid imaging and prognosis

Schenker et al (2008)[101] demonstrated that with PET/CT, in case of normal PET scan and no coronary calcification the annual rate for cardiac death and/or MI was 2.6% which increase to 12.3% with calcium score of ≥1000.

Challenges and advantages

Combined technology offers higher diagnostic performance and provides clinicians with anatomic and functional information in single setting. Limitations include cost and higher radiation. Thus, it is essential to choose suitable candidates.92 However, current prospective ECG gating CTA protocols have been introduced in practice which help to reduce radiation up to 70% with maintained diagnostic accuracy.[102,103]

Conclusion

Proper management of patients with suspected CAD requires accurate diagnosis and risk stratification. Currently many non-invasive imaging are available, providing complementary information about anatomical and functional significance of CAD. By reducing the number of unnecessary invasive tests with their potential adverse events and because of their prognostic value, non-invasive imaging modalities are considered cost-effective. Choosing the appropriate test depends on pre-test probability, patients' characteristics, suitability for the test, availability and local expertise. Ideal patients are those at intermediate pre-test likelihood for CAD.[8] Overall, all non-invasive imaging tests provide satisfactory sensitivities and specificities. For initial assessment of patients suspected of CAD, both stress echocardiography and nuclear perfusion imaging are indicated as they showed comparable diagnostic accuracy and choosing one of them depends on availability. However, stress echocardiography remains the initial in most setting due to its wide availability, feasibility and its lack of radiation. Stress CMR with dobutamine is an alternative for patients with poor Echo image quality. In addition, perfusion CMR has shown higher sensitivity compared to SPECT but with no radiation. CTCA provides impressive image quality of the coronary arteries with excellent sensitivity and NPV for excluding significant CAD. [8] Finally, hybrid imaging is a promising technology that allows anatomical and functional evaluation of CAD in single setting and guide clinicians for the most appropriate management option. Summary results of

Table: Diagnostic accuracy of non-invasive imaging for identification of CAD.

Cardiac imaging modality	Sensitivity (%)	Specificity (%)	PPV	NPV
Exercise ECHO [17]	82.6%	84.4%	–	–
Dobutamine ECHO [13]	86%	86%	–	–
SPECT [39]	88.3%	75.8%	–	–
PET [39]	92.6%	81.3%	–	–
Stress wall motion CMR [53]	83%	86%	–	–
Perfusion CMR [39]	89%	80%	–	–
64-MDCT [75]	99%	89%	93%	100%
320-MDCT [79]	95.4%	94.7%	94.4%	94.5%

diagnostic accuracy of non-invasive imaging techniques are shown in the table above.

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