Use of coronary CT angiography in the diagnosis of patients with suspected coronary artery disease: findings and clinical indications

Zhong-Hua Sun[1], Yu-Pin Liu[2], Dong-Jin Zhou[2], Yan Qi[2]

[1]*Discipline of Medical Imaging, Department of Imaging and Applied Physics, Curtin University, GPO Box, U1987, Perth, Western Australia 6845, Australia*
[2]*Department of Imaging, Chinese Traditional Medicine Hospital of Guangdong Province, Guangzhou, China*

Abstract

   Objective   To investigate the clinical applications of coronary CT angiography in patients with suspected coronary artery disease and identify factors that affect CT findings. **Methods**   Medical records of patients suspected of coronary artery disease over a period of 12 months from a tertiary teaching hospital were retrospectively reviewed. Patient age, sex (male/female), duration of symptoms and abnormal rates of coronary CT angiography scans were analysed to investigate the relationship among these parameters. The patients by age were characterized into five groups: under 36 years, 36−45 years, 46−55 years, 56−65 years and more than 66 years, respectively; while the duration of symptoms was also classified into five groups: less than one week, one week to one month, one to three months, three to six months and more than six months. **Results**   Of the 880 patient records reviewed, 800 met the above study criteria. Five hundred and forty nine patients demonstrated abnormal CT findings (68.6%). There was no significant difference in the percentage of abnormal CT findings based on patient sex and the duration of symptoms ($P = 0.14$). The abnormal rates of coronary CT angiography, however, increased significantly with increasing age ($P < 0.001$); with patients over 65 years of age 2.5 times more likely to have an abnormal CT scan relative to a patient under 45 years. A significant difference was found between abnormal coronary CT angiography and the duration of symptoms ($P = 0.012$). **Conclusions**   Our results indicate coronary CT angiography findings are significantly related to the patient age group and duration of symptoms. Clinical referral for coronary CT angiography of patients with suspected coronary artery disease needs to be justified with regard to the judicious use of this imaging modality.

1   Introduction

   Coronary artery disease (CAD) is the leading cause of death in many advanced countries with its prevalence increasing among developing countries.[1,2] In 2001, CAD was responsible for 7.3 million deaths and 58 million disability-adjusted life years lost worldwide.[3] Invasive coronary angiography is widely used as a reliable technique to diagnose CAD due to its superior spatial and temporal resolution. However, it is an invasive and expensive procedure with associated morbidity and mortality.[4] Over the last decades, use of non-invasive imaging modalities in CAD has undergone rapid developments, such as multi-slice CT (MSCT), magnetic resonance imaging (MRI) and radio-nuclide imaging, including single photon emission computed tomography (SPECT) and positron emission tomography (PET).[5−8] Although promising results have been achieved with cardiac MRI, it is not considered suitable for routine clinical use in the diagnosis of CAD. Myocardial perfusion imaging with SPECT or PET is a widely established method for non-invasive evaluation of coronary artery stenosis.[9−11] However, the most important applications of SPECT and PET are in the diagnostic workup and management of patients with CAD, such as prediction of disease prognosis, selection of patients for revascularisation and assessment of acute coronary syndromes. In comparison, the application of MSCT in the diagnosis of CAD, which is currently defined as coronary CT angiography (CCTA), allows for excellent visualization of anatomical details of the coronary artery and its branches, and is the only imaging modality which has been widely used in the diagnosis of CAD with high diagnostic accuracy.[12,13]

   Numerous studies have shown that CCTA has a high diagnostic accuracy for the detection of significant CAD

Correspondence to: Zhong-Hua Sun, PhD, Associate Professor, Discipline of Medical Imaging, Department of Imaging and Applied Physics, Curtin University, GPO Box, U1987, Perth, Western Australia 6845, Australia.
E-mail: z.sun@curtin.edu.au

when compared to invasive coronary angiography.[13-16] High quality CCTA (64-slice and higher) is not only able to provide reliable information on coronary luminal changes, but also has the potential to visualize morphological changes of the coronary artery wall, characterize atherosclerotic plaques and identify non-stenotic plaques which may not be detected by invasive coronary angiography.[17–19] Despite satisfactory results achieved with coronary CT angiography, CCTA has the disadvantage of high radiation dosing, which leads to the concern of radiation-associated risks.[20–22] Radiation-induced malignancy as a consequence of the radiation dose is a problem that has been addressed by the National Research Council of the United States.[23] As the use of cardiac CT continues to grow, particularly in young adult patients, concerns over the population exposed to high dose from CT are being widely expressed in the scientific literature.[20–22,24] It has become clear the responsible use of CT is absolutely necessary in terms of justifying and adjusting scanning techniques. The purpose of this study was to determine whether CCTA imaging of patients with suspected CAD is appropriately used by clinicians in the current clinical practices in a major teaching hospital, and explore the factors that influence the use of CCTA for imaging patients suspected of CAD as the target group.

2   Methods

2.1   Retrieval of data from medical records

Medical records with CCTA scans over 12 months (2009–2010) from a tertiary hospital in Southern China were retrospectively reviewed of patients presenting with chest discomfort/chest pain, hypertension or diabetes with suspected CAD. For this study, the inclusion criterion was patients presenting with chest discomfort as an isolated symptom. Patients with chest trauma, prior thoracic surgery (coronary stenting or coronary artery bypass grafts) were excluded. A total of 880 patient records were queried, and the following information was assessed based on these records: patient age group, sex, duration of symptoms and percentage of abnormal CCTA findings. Common risk factors related to the CAD, such as hypertension, and diabetes mellitus were also checked for each patient based on the request forms to assist in further analysis of any relationship to the presence of abnormal findings.

2.2   Coronary CT angiography scanning protocol

All CT scans were performed on a 64-slice CT scanner (GE Medical Systems, Lightspeed VCT, 64 × 0.625 mm) with the following protocols: beam collimation 0.625 mm, pitch 0.18, reconstruction interval of 0.625 mm, with tube

voltage of 120 kV and tube current ranging from 300 mAs to 650 mAs (tube current modulation). Contrast medium (Iopamiro, 370, 60–80 mL) was injected onto the ante-cubital vein at 5 mL/s followed by 30 mL of saline chasing at 3 mL/s, and the scan was performed with a bolus tracking technique with a CT attenuation of 250 HU as the triggering threshold at the ascending aorta to initiate the scan.

Axial images were reconstructed with a slice thickness of 0.625 mm in 0.625 mm increment resulting in isotropic volume data with a voxel size of 0.625 mm × 0.625 mm × 0.625 mm. Retrospective electrocardiographic-gating protocol was used in all patients to acquire the volume data achieving a temporal resolution of 175 ms in the centre of the gantry rotation. Most volume data were reconstructed at 70%–80% RR interval to minimize artifacts. In some patients, the volume data were reconstructed at 45% RR interval to acquire better image quality of the right coronary artery and at 75% RR interval to better demonstrate the left anterior descending artery. For patients with a heart rate more than 70 beats/min, a beta-blocker was used to slow down the heart rate.

2.3   Characterization of patient groups and data analysis

Based on categories by different ages and duration of symptoms, we characterized the patents by age into five groups, namely, under 36 years, 36–45 years, 46–55 years, 56–65 years and over 65 years, respectively. Similarly, the duration of symptoms was also divided into five groups: less than one week, one week to one month, one month to three months, three months to six months and more than six months.

Abnormality of coronary arteries refers to atherosclerotic changes identified on CCTA scans, which is reflected in either an involvement of the right coronary artery (RCA), or the left coronary artery (LCA), or both of RCA and LCA. The involvement of LCA includes abnormal changes to the left main stem, left anterior descending and left circumflex as well as side branches; while involvement of both RCA and LCA refers to abnormal changes at both of these arteries including side branches. Significant coronary stenosis indicates more than 50% lumen stenosis due to the presence of plaques.

2.4   Statistical analysis

The outcome of the CCTA scan, expressed as a binary variable (no abnormality detected; abnormality detected), was treated as the dependent or response variable in a logistic regression analysis to examine the effects, if any, of three explanatory factors, as follows: sex of patient; age at onset of symptom(s) (five bands); and duration of symptom(s)

(five bands). This methodology facilitates testing for the presence of factor interaction effects, in addition to factor main effects. Between-group differences were tested using the Mantel-Haenszel Chi-squared test with *n*-1 degree of freedom (*n* is the number of groups). Significance tests were conducted at the 5% level of significance. The analyses were computed with the NCSS 2007 statistical computer package (NCSS, LLC. Kaysville, Utah. www.ncss.com).

3 Results

Of the 880 patient records reviewed, 800 met the selection criterion. The age range of these patients was from 15 to 85 years. Five hundred and forty nine out of 800 scans (68.6%) were abnormal, with 315 out of 449 scans (70.0%) of males being abnormal, and 234 out of 351 scans (66.7%) of females being abnormal. Chest pain or chest discomfort was the most common symptom (63.0%) recorded on the CT request form, while 21.0% of patients reported a history of hypertension, and 8.0% of these patients also had diabetes. Eight percents of patients presented tachycardia, and 7.6% had dizziness as the initial symptoms.

Table 1 lists the abnormal CCTA findings corresponding with patient sex, age groups and duration of symptoms. There was no significant difference in the percentage of abnormal CCTA findings between male and female patients ($P = 0.29$). Similarly, no significant difference was found between the sex (male/female) and duration of symptoms ($P = 0.14$). However, a statistically significant difference was confirmed between the patient age group and abnormal CCTA findings ($P < 0.001$). Figure 1 shows that only one-third of the CCTA scans were abnormal for the age groups of

under 36 years and 36–45 years, while the percentage of abnormal CT findings increased to more than 50% in the age group more than 46 years. Relative to a patient under 45 years, a patient aged over 65 years was 2.5 times as likely to have an abnormal CCTA scan. CCTA findings were also closely related to the duration of symptoms, with significant differences between abnormal CT findings and duration of symptoms ($P = 0.012$), as shown in Figure 2.

The two lowest age groups (under 36 and 36–45 years groups) were combined in the analysis of coronary artery involvement because of an unacceptably small expected cell frequency. A significant difference was found between patient age distribution and coronary artery involvement ($P < 0.001$). Figure 3 shows a direct correlation between age groups and abnormal coronary changes. The highest abnormal rates of coronary involvement of LCA, RCA and RCA/LCA were noticed in the age group over 65 years old. There was no correlation between the involvement of coronary arteries and the duration of symptoms for over 65 years age group ($P = 0.65$).

Of these patients with abnormal changes to the coronary arteries, the number of significant coronary stenosis was directly related to the age group, as less than 15% of patients under 56 years had significant coronary stenosis, but this was increased to 29% and 38% in the age groups of 56–65 years and over 66 years, respectively. Of all abnormal observations, significant coronary stenosis was only observed in 28% of patients. No correlation was found between the abnormal coronary changes and the duration of symptoms. Figure 4 is an example of normal CCTA scan in a patient with chest discomfort, while Figure 5 shows significant coronary stenosis in a patient with chest pain and hypertension.

Table 1. Characteristics of coronary CT angiography in patients with suspected coronary artery disease.

	Total number	Abnormal number	Male/Female (numbers)	RCA abnormal change (numbers)	LCA Abnormal change (numbers)	LCA/RCA abnormal change (numbers)	Number of significant stenosis
Age groups							
Under 36 years	15	5	13/2	0	4	0	0
36–45 years	68	23	55/13	4	12	7	3
46–55 years	200	117	119/81	12	68	37	10
56–65 years	227	156	119/108	11	74	71	45
Over 65 years	290	248	143/147	13	96	139	94
Patient's sex							
Male	449	315					
Female	351	234					
Duration of symptoms							
Less than 1 week	55	30	33/22	3	16	11	6
1 wk to 1 moth	58	37	35/23	2	21	14	9
1–3 moth	39	26	28/11	4	12	10	6
3–6 moth	29	20	16/13	1	8	11	5
More than 6 moth	338	256	176/162	16	124	116	28

* For the remaining 281 patients, the duration of symptoms is not available. LCA: left coronary artery; RCA: right coronary artery,.
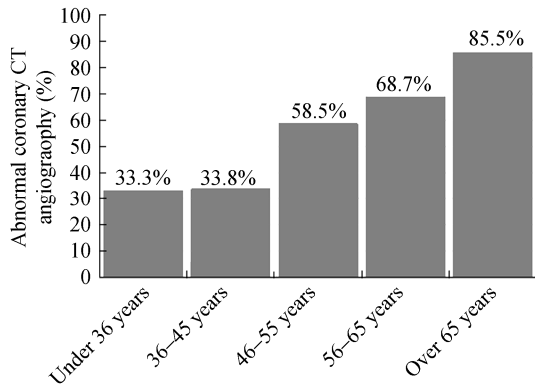
Figure 1. Percentage of abnormal coronary CT angiography in relation to five different age groups. The abnormal CT rates increased significantly with the increase of patient age, reaching the highest percentage when patients were over 65 years old.
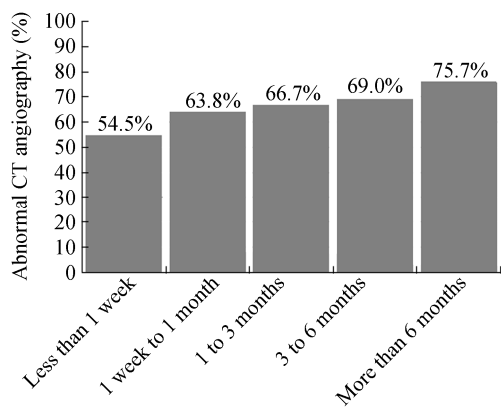

Figure 2. Percentage of abnormal coronary CT angiography in relation to five different durations of symptoms. The abnormal CT rates increased significantly with the increase of duration of symptoms.
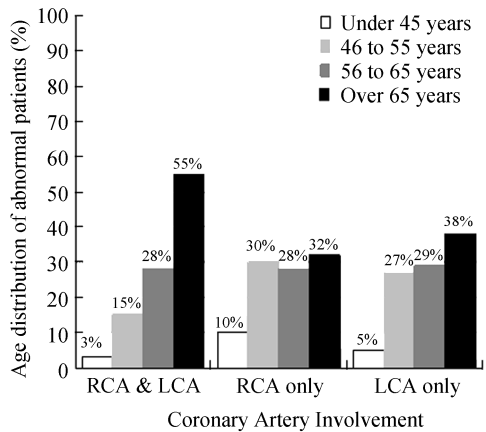

Figure 3. Percentage of coronary artery involvement in relation to four different age groups. The abnormal rates of coronary involvement increased significantly with the increase of patient's age, reaching the highest percentage when the patients were over 65 years old.
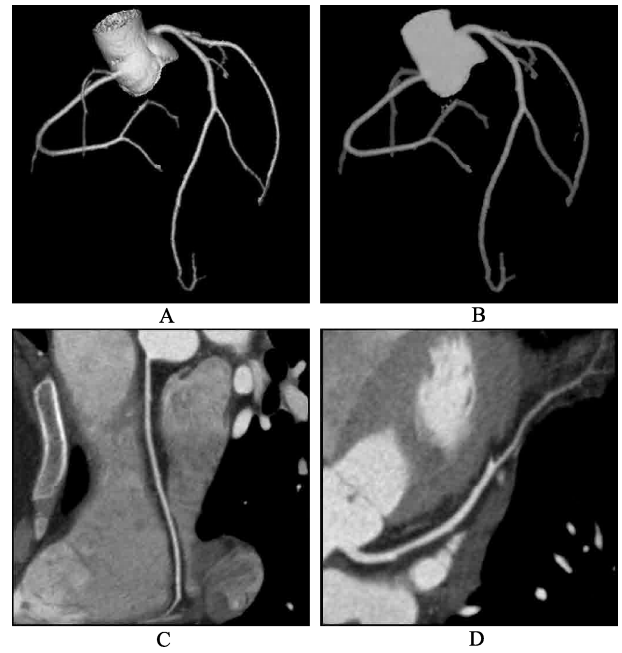

Figure 4. Coronary CT angiography shows normal findings in a 18-year-old female with chest discomfort after exercise for six years. Normal coronary arteries are clearly demonstrated in 3D volume rendering (A), maximum-intensity projection (B) and curved planar reformatted images (C and D).
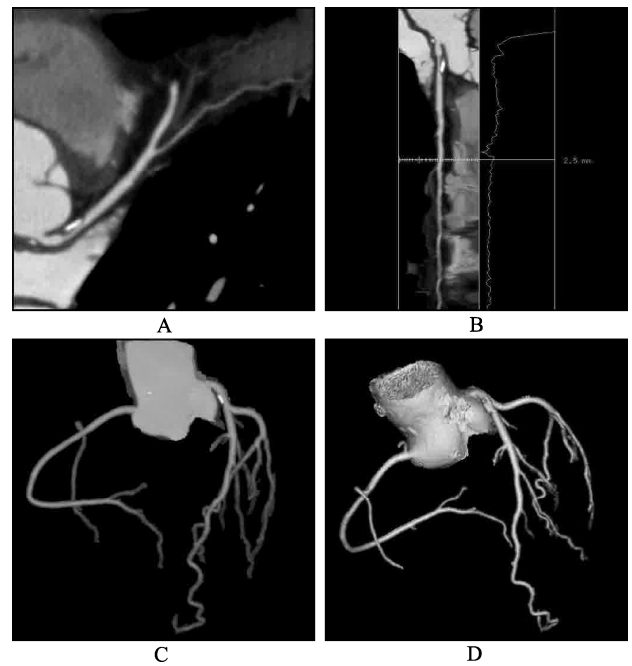

Figure 5. Coronary CT angiography shows significant stenosis in the left anterior descending (LAD) in a 78-year-old man with history of chest pain and hypertension for two years. A mixed plaque is present at the proximal segment of LAD with more than 50% lumen stenosis, as visualized on curved planar reformatted (A), curved planar reformation with coronary straightening (B), maximum intensity projection (C) and volume rendering (D) images.

4   Discussion

This study highlights three important findings considered valuable for current clinical practice with regard to the judicious use of coronary CT angiography. Firstly, the abnormal CCTA findings in patients with suspected CAD are directly related to the age group, indicating that CCTA should be selectively recommended for imaging elderly patients presenting with chest discomfort. Secondly, the duration of symptoms is closely related to the abnormal CCTA findings, with patients presenting with symptoms of more than 6 months demonstrating the highest percentage of abnormal CT findings. Thirdly, there is a direct correlation between involvement of coronary arteries and patient age group, with patients over 65 years old found to have abnormal changes, including significant stenosis to the LCA, RCA and RCA/LCA, and higher rates than any other age group.

Coronary CT angiography is one of the most exciting developments in recent years in the diagnosis of CAD. The use of both non-invasive and invasive studies has increased substantially, and the cost of imaging services has doubled from 2000 to 2006 according to the Government report in the United States,[25] with $14.1 billion in Medicare spending for imaging services (www.gao.gov/products/ GAO-08-452). The increased use of non-invasive imaging should aim for more effective risk stratification of patients, allowing identification of those patients who would most likely benefit from invasive coronary angiography and ideally reduce the number of invasive procedures in patients who do not have obstructive disease. Thus, the key role of CCTA should be defined clearly by physicians (mainly cardiologists) as to when this technique is appropriately selected for diagnostic purposes.

However, current clinical and imaging algorithms are suboptimal with regard to the proper identification of patients with obstructive CAD and judicious use of CCTA as a risk stratification approach.[26] Shreibati *et al*.[27] compared utilization and spending associated with CCTA and myocardial perfusion testing based on a large sample of the Medicare population. Their data suggest increased use of CCTA may significantly increase subsequent diagnostic testing and invasive cardiac procedures such as cardiac catheterization and subsequent coronary revascularization. This increased use of invasive procedures after CCTA leads to substantially higher costs for medical care than that after myocardial stress testing. Their observation is supported by other studies highlighting the necessity of the development of practice guidelines that can endorse the proper clinical application of CCTA, especially in younger patients.[26-29]

Our results are consistent with the literature reports as increased abnormal CCTA findings were confirmed in the elderly population. Significant stenosis is only observed in less than 30% of the patients with more than 60% being reported in the patients over 65 years. This emphasizes the importance of appropriately utilizing CCTA in different age groups.

Due to rapid technological developments of MSCT, researchers expressed concern about the "exploding use" of CCTA and that we do not yet know enough about how it changes patient management or leads to better outcomes.[30,31] Due to very high negative predictive value (> 95%), CCTA has been claimed to act as a gatekeeper and reduce invasive coronary angiography rates. However, there are no reported data to support this hypothesis. The new Appropriateness Criteria applied to CCTA reported the use of cardiac CT/MR for anatomy and function and for diagnosis in symptomatic patients at intermediate risk for CAD is appropriate, but repeat testing and general screening applications were considered less favourably.[32,33] Moreover, because symptomatic patients with CAD will be referred to coronary angiography for possible stent placement, it seems unlikely that CCTA will reduce the number of coronary angiography examinations. The main concern is that CCTA will be increasingly used in asymptomatic, low-risk patients, as shown in this study. However, after a CCTA, the portion of this group with positive findings, whether true-positive or false-positive, most likely will be referred for coronary angiography.[27] In addition, there are no data available showing benefits of revascularization for asymptomatic patients. Thus, use of CCTA in low-risk patients needs to be justified.

Although CCTA is non-invasive compared with coronary angiography, it is not without risks. The estimated radiation dose for a 16-slice CCTA scan is between 4 mSv and 24.2 mSv, and for 64-slice scan is between 3 mSv and 26.7 mSv, depending on whether electrocardiographic pulsing or dose-saving strategy is used and on the gender of the patient (radiation doses are higher in women).[34,35] Of various dose-saving strategies used in coronary CT angiography,[20,36-39] prospective ECG-triggered CCTA represents one of the most promising radiation saving techniques with a significant reduction of radiation dose when compared to the retrospective ECG-gating and invasive coronary angiography. The mean effective radiation dose for prospective ECG-triggered CCTA in patients with a low and regular heart rate has been reported to range from 2.7 mSv to 4.5 mSv, which is significantly lower than for retrospective ECG-gated CCTA. In comparison, the radiation dose for invasive coronary angiography is between 3 mSv and 9 mSv.[40] Brenner and

Hall[22] estimated approximately 1.5% to 2.0% of all cancers in the United States may be caused by radiation exposure from CT examinations. In the UK, Davies *et al*.[41] estimated radiation from CT scans causes 800 cancers a year in women and 1300 in men. Radiation exposure is especially important for young and female patients, as radiation effects in young patients and women are more severe than in older individuals and in men, so that prevention of overly high radiation doses are most important in young individuals. A recent study reported one in 270 women aged 40 years who undergo coronary CT angiography will develop cancer.[42] Since our results show no significant difference between patient gender and duration of symptoms and abnormal CCTA findings, it is very likely that female patients are exposed to more radiation doses due to unnecessary CT scans, based on this analysis.

There are some limitations in this study that need to be acknowledged. Firstly, data collection was restricted to only one imaging center, thus, a biased opinion could be introduced, as clinical practice (routine referral of imaging modalities) is variable among different centers. Secondly, CCTA results were extracted based on diagnostic reports without further correlation with coronary angiography (diagnostic accuracy and clinical significance or interventional procedures), thus, whether patients required medical intervention could not be determined alone based on the CCTA findings. Thirdly, only the atherosclerotic anatomical changes rather than plaque composition were assessed by CCTA in this study. However, it is widely accepted that plaque composition rather than the degree of luminal narrowing may be predictive of the patient's risk for cardiac events. Previous reports on detection and characterization of coronary atherosclerotic plaque have shown that CCTA enabled the measurement of the degree of stenosis and was well correlated with measurements by intravascular ultrasound and coronary angiography.[43-45] Future studies are needed to compare coronary plaque burden and composition with subsequent clinical outcomes. Lastly, radiation dose reports were not available in this study, which is another major limitation. Although higher radiation exposure to patients could be expected from the retrospective ECG-gated CCTA used in this group of patients, it is necessary to compare the radiation dose with CCTA findings in terms of image quality and diagnostic accuracy, so that dose-reduction strategies can be recommended in future patient scans.

In conclusion, our study shows that coronary CT angiography findings are directly related to patient age and duration of symptoms, with increased abnormal findings reported in elderly population with duration of symptoms more than three months. Moreover, there is a direct correlation between the involvement of coronary arteries and the patient age. Use of coronary CT angiography in the diagnosis of patients with suspected coronary artery disease needs to be justified clinically, since a low percentage of positive results are reported in younger patients. Further studies with inclusion of clinical predictive outcomes should be conducted to verify our preliminary results.

References

1   Lloyd-Jones D, Adams RJ, Brown TM, *et al*. Executive summary: heart disease and stoke statistics 2010 update: A report from the American Heart Association. *Circulation* 2010; 121: 948–954.

2   Gaziano TA, Bitton A, Anand S, *et al*. Growing epidemic of coronary heart disease in low-and middle-income countries. *Curr Probl Cardiol* 2010; 35: 72–115.

3   WHO. The World Health Report 2002: Reducing Risks, Promoting Healthy Life. World Health Organization: Geneva, 2002.

4   Noto TJ Jr, Johnson LW, Krone R, *et al*. Cardiac catheterization 1990: a report of the registry of the Society for Cardiac Angiography and Interventions. (SCA&I). *Cathet Cardiovasc Diagn* 1991; 24: 75–83.

5   Sommer T, Hackenbroch M, Hofer U, *et al*. Coronary MR angiography at 3.0 T versus that at 1.5 T: initial results in patients suspected of having coronary artery disease. *Radiology* 2005; 234: 718–725.

6   Van der Vaart MG, Meerwaldt R, Slart RHJA, *et al*. Application of PET/SPECT imaging in vascular disease. *Eur J Vasc Endovasc Surg* 2008; 35: 507–513.

7   Husmann L, Wiegand M, Valenta I, *et al*. Diagnostic accuracy of myocardial perfusion imaging with single photon emission computed tomography and positron emission tomography: a comparison with coronary angiography. *Int J Cardiovasc Imaging* 2008; 24: 511–518.

8   Al Moudi M, Sun Z, Lenzo M. Diagnostic value of SPECT, PET and PET/CT in the diagnosis of coronary artery disease: A systematic review. *Biomed Imaging Interv J* 2011; 7: E9.

9   Hachamovitch R. Comparison of the short-term survival benefit associated with revascularization compared with medical therapy in patients with no prior coronary artery disease undergoing stress myocardial perfusion single photon emission computed tomography. C*irculation* 2003; 107: 2900–2906.

10 Hachamovitch R, Berman DS, Shaw LJ, *et al*. Incremental prognostic value of myocardial perfusion single photon emission computed tomography for the prediction of cardiac death:

differential stratification for risk of cardiac death and myocardial infarction. *Circulation* 1998; 97: 535–543.

11 Santana CA, Folks RD, Garcia EV, *et al*. Quantitative 82Rb PET/CT: Development and validation of myocardial perfusion database. *J Nucl Med* 2007; 48: 1122–1128.

12 Sun Z, Jiang W. Diagnostic value of multislice CT angiography in coronary artery disease: A meta-analysis. *Eur J Radiol* 2006; 60: 279–286.

13 Sun Z, Lin CH, Davidson R, *et al*. Diagnostic value of 64-slice CT angiography in coronary artery disease: A systematic review. *Eur J Radiol* 2008; 67: 78–84.

14 Miller JM, Rochitte CE, Dewey M, *et al*. Diagnostic performance of coronary angiography by 64-row CT. *N Engl J Med* 2008; 359: 2324–2336.

15 Budoff MJ, Dowe D, Jollis JG, *et al*. Diagnostic performance of 64-multidetector row coronary computed tomographic angiography for evaluation of coronary artery stenosis in individuals without known coronary artery disease: results from the prospective multicenter ACCURACY (Assessment by Coronary Computed Tomographic Angiography of Individuals Undergoing Invasive Coronary Angiography) trial. *J Am Coll Cardiol* 2008; 52: 1724–1732.

16 Meijboom WB, Meijs MFL, Schuijf JD, *et al*. Diagnostic accuracy of 64-slice computed tomography coronary angiography: a prospective multicenter, multivendor study. *J Am Coll Cardiol* 2008; 52: 2135–2144.

17 Sun Z, Dimpudus F, Nugroho J, *et al*. CT virtual intravascular endoscopy assessment of coronary artery plaques: a preliminary study. *Eur J Radiol* 2010; 75: E112–E119.

18 Harada K, Amano T, Uetani T, *et al*. Accuracy of 64-slice multidetector computed tomography for classification and quantitation of coronary plaque: comparison with integrated backscatter intravascular ultrasound. *Int J Cardiol* 2011; 149: 95–101.

19 Sun Z, Cao Y, Li H. Multislice computed tomography angiography in the diagnosis of coronary artery disease. *J Geriatr Cardiol* 2011; 8: 104–113.

20 Paul JF, Abada HT. Strategies for reduction of radiation dose in cardiac multislice CT. *Eur Radiol* 2007; 17: 2028–2037.

21 Hausleiter J, Meyer T, Hermann F, *et al*. Estimated radiation dose associated with cardiac CT angiography. *JAMA* 2009; 301: 500–507.

22 Brenner DJ, Hall EJ. Computed tomography—an increasing source of radiation exposure. *N Engl J Med* 2007; 357: 2277–2284.

23 BEIR National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation (BEIR) Report VII 2006 Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII–Phase 2. National Research Council: Washington DC, USA.

24 Sun Z, Choo GH, Ng KH. Coronary CT angiography: current status and continuing challenges. *Br J Radiol* 2012; 85: 495–510.

25 Lucas FL, DeLorenzo MA, Siewers AE, *et al*. Temporal trends in the utilization of diagnostic testing and treatments for cardiovascular disease in the United States, 1993–2001. *Circulation* 2006; 113: 374–379.

26 Min JK, Shaw LJ, Berman DS. The present state of coronary computed tomography angiography: a process in evolution. *J Am Coll Cardiol* 2010; 55: 957–965.

27 Shreibati JB, Baker LC, Hlatky MA. Association of coronary CT angiography or stress testing with subsequent utilization and spending among medicare beneficiaries. *JAMA* 2011; 306: 2128–2136.

28 Nielsen LH, Markenvard J, Jensen JM, *et al*. Frontline diagnostic evaluation of patients suspected of angina by coronary computed tomography reduces downstream resource utilization when compared to conventional ischemia testing. *Int J Cardiovasc Imaging* 2011; 27: 813–823.

29 McEvoy JW, Blaha MJ, Nasir K, *et al*. Impact of coronary computed tomographic angiography results on patient and physician behavior in a low-risk population. *Arch Intern Med* 2011; 171: 1260–1268.

30 Redberg RF, Walsh J. Pay now, benefits may follow: the case of cardiac computed tomographic angiography. *N Engl J Med* 2008; 359: 2309–2311.

31 Redberg RF. Computed tomographic angiography: more than just a pretty picture? *J Am Coll Cardiol* 2007; 49: 1827–1829.

32 Patel MR, Spertus JA, Brindis RG, *et al*. ACCF proposed method for evaluating the appropriateness of cardiovascular imaging. *J Am Coll Cardiol* 2005; 46: 1606–1613.

33 Hendel R, Patel M, Kramer C, Poon M. Appropriateness criteria for cardiac computed tomography and cardiac magnetic resonance imaging. *J Am Coll Cardiol* 2006; 48: 735–1097.

34 Sabarudin A, Sun Z, Ng KH. A systematic review of radiation dose associated with different generations of multidetector CT coronary angiography. *J Med Imag Radiat Oncol* 2012; 56: 5–17.

35 Coles DR, Smail M, Negus I, *et al*. Comparison of radiation doses from multislice computed tomography coronary angiography and conventional diagnostic angiography. *J Am Coll Cardiol* 2006; 47: 1840–1845.

36   Schoenhagen P, Thompson CM, Halliburton SS. Low-dose cardiovascular computed tomography: where are the limits? *Curr Cardiol Rep* 2012; 14: 17–23.

37   Schoenhagen P. Back to the future: coronary CT angiography using prospective ECG triggering. *Eur Heart J* 2008; 29: 153–154.

38   Sun Z, Ng KH. Diagnostic value of coronary CT angiography with prospective ECG-gating in the diagnosis of coronary artery disease: A systematic review and meta-analysis. *Int J Cardiovasc Imaging.* Published Online First: Jan 4 2012. DOI 10.1007/s10554-011-0006-0.

39   Sun Z, Ng KH. Prospective versus retrospective ECG-gated multislice CT coronary angiography: A systematic review of radiation dose and diagnostic accuracy. *Eur J Radiol* 2012; 81: E94–E100.

40   Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. www.undemocracy.com/A-63-398.pdf (Access in April 2012).

41   Davies HE, Wathen CG, Gleeson FV. Risks of exposure to radiological imaging and how to minimise them. *BMJ* 2011; 342: 589–593.

42   Smith-Bindman R, Lipson J, Marcus R, *et al*. Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. *Arch Intern Med* 2009; 169: 2078–2086.

43   Achenbach S, Moselewski F, Ropers D, *et al*. Detection of calcified and non-calcified coronary atherosclerotic plaque by contrast-enhanced, submillimeter multi-detector spiral computed tomography: a segment based comparison with intravascular ultrasound. *Circulation* 2004; 109: 14–17.

44   Kim SY, Kim KS, Lee YS, *et al*. Assessment of non-calcified coronary plaques using 64-slice computed tomography: comparison with intravascular ultrasound. *Korean Circ J* 2009; 39: 95–99.

45   Cury RC, Pomerantsev EV, Ferencik M, *et al*. Comparison of the degree of coronary stenoses by multi-detector computed tomography versus by quantitative coronary angiography. *Am J Cardiol* 2005; 96: 784–787.