Over the last decade, a great deal of interest has been focused on imaging and diagnosis of coronary artery disease (CAD) using coronary computed tomography angiography (CCTA), due to its less invasive nature and improved spatial and temporal resolution. Moderate–high diagnostic accuracy has been achieved with 64-, or more, slice computed tomography (CT), owing to further technical improvements [1–5]. These studies have indicated that CCTA has high accuracy for the diagnosis of CAD and could be used as an effective alternative to invasive coronary angiography in selected patients [6].

In addition to the diagnostic value, CCTA demonstrates the potential to visualize coronary artery wall morphology, characterize atherosclerotic plaques and identify nonstenotic plaques. Studies have shown that CCTA demonstrates high prognostic value in CAD, as it is able to differentiate low-risk from high-risk patients [7,8], with a very low rate of adverse cardiac events occurring in patients with normal CCTA, and a significantly high rate of these events in patients with obstructive CAD.

CCTA with 3D visualization has been explored as a new imaging modality for the assessment of cardiac valves, including both original and artificial ones [9–11]. Transesophageal echocardiography and transthoracic echocardiography are the primary imaging modalities for valve assessment as these techniques provide both anatomical and functional information. However, they fail to detect the anatomical substrate that causes prosthetic heart valve dysfunction [10]. CCTA, with its capability to produce 3D/4D visualizations, is emerging as a new diagnostic modality for the evaluation of heart valve morphology and function.

Despite these promising reports, CCTA has the disadvantage of having a high-dose radiation, which leads to the concern of radiation-induced malignancy [12,13]. It is generally agreed that CT is an imaging modality with high radiation exposure, as it contributes up to 70% of the radiation dose of all radiological examinations, although it comprises only 15% of all radiological examinations. Radiation-associated risk is a problem that has been addressed by the National Research Council of the USA [14], and there is an increased awareness of radiation risk associated with CCTA among physicians and manufacturers, which is reflected in the changing research directions from the early research focus on the diagnostic value of CCTA in CAD to the increasingly reported studies on dose reduction in the literature [15]. The purpose of this paper is to provide an overview of the clinical applications of CCTA in coronary artery disease with focus on the diagnostic and predictive value of CCTA; technical developments in cardiac computed tomography imaging and different approaches to radiation dose reduction.

**KEYWORDS:** coronary artery disease, CCTA, diagnostic value, predictive value, radiation dose

Zhonghua Sun* & Mansour Almoudi

1Discipline of Medical Imaging, Department of Imaging & Applied Physics, Curtin University, Perth, GPO Box U1987, Western Australia 6845, Australia

*Author for correspondence: Tel.: +61 8 9266 7509 Fax: +61 8 9266 2377 z.sun@curtin.edu.au

**Coronary computed tomography angiography: an overview of clinical applications**

High diagnostic accuracy has been achieved with coronary computed tomography angiography (CCTA) using 64-, and more, slice computed tomography scanners, and in selected patients, CCTA is considered a reliable alternative to invasive coronary angiography. CCTA is able to detect variable densities in the coronary atherosclerotic plaques and demonstrate the corresponding intraluminal changes due to the presence of plaques, thus providing prognostic information of disease extent. Despite the tremendous contributions of CCTA to cardiac imaging, CCTA is associated with high-dose radiation, which has raised serious concerns in the literature. The aim of this review is to provide an overview of the clinical applications of CCTA in coronary artery disease with focus on the diagnostic and predictive value of CCTA; technical developments in cardiac computed tomography imaging and different approaches to radiation dose reduction.

The history of cardiac CT is closely related to technological improvements that occurred with
each successive generation of CT scanners. Imaging of the heart has become clinically practicable with the introduction of multislice CT angiography (MSCT) and development of ECG-synchronized gating and the z-axis extended coverage from the MSCT scanners [16,17]. The technological developments in these MSCT scanners determine the diagnostic performance of CCTA in terms of spatial and temporal resolution, which, in turn decides the diagnostic value of CCTA in CAD. This is discussed in detail in the following sections.

Four- & 16-slice CCTA
The early generations of four- and 16-slice CT scanners represented a technological revolution in cardiac imaging [18–20], although the diagnostic accuracy in terms of sensitivity was low for determining the degree of CAD. Specificity for exclusion of CAD (in particular, the negative predictive value) was good and this generation of technology also proved useful for the evaluation of coronary anomalies and bypass graft patency. Improved spatial resolution with 16-slice CT plays an important role in the reliable detection and characterization of coronary plaques and cardiac wall changes (such as remodeling of the coronary wall due to atherosclerotic plaques). Improved spatial (0.75 vs 1–1.25 mm) and temporal resolution (105–210 vs 165–330 ms) can be obtained with 16-slice CT when compared with the early type of four-slice CT scanners [21,22]. However, the image quality is compromised in patients with a high heart rate, or with stents or severely calcified arteries [23,24]. In order to overcome the limitations of 16-slice CT, multisegment reconstruction was used to improve the temporal resolution to 93 ms compared with the 185 ms acquired with the standard half-scan reconstruction [25]. Diagnostic accuracy of multisegment reconstruction has been improved due to a reduction in motion artifacts, but at the expense of high radiation exposure resulting from a lower pitch [25,26].

64-slice CCTA
In 2004, all major CT manufacturers introduced the next generation of MSCT scanners with 32, 40 and 64 simultaneously acquired slices, which brought about a further leap in volume coverage speed in cardiac CT imaging. With gantry rotation times being down to 330 ms for 64-slice, the spatial (0.5–0.6 mm) and temporal resolution (up to 165 ms) for cardiac ECG-gated imaging is again markedly improved, thus, enabling longitudinal cardiac coverage (3.2–4.0 cm for 64-slice CT vs 1.2 cm for 16-slice CT).

The increased temporal resolution of 64-slice CT has the potential to improve the clinical strength of ECG-gated cardiac examinations at higher heart rates, thereby reducing the number of patients requiring heart rate control. In contrast to previous studies, high diagnostic accuracy has been achieved despite the presence of severely calcified coronary plaques [27,28]. In addition, using a 64-slice CT, the scanning time is reduced to less than 35 s, allowing a decreased breath-hold time, better utilization of contrast medium with fewer enhancements of adjacent structures and a lower dose of applied contrast medium [24]. Improvement of image quality has also been reported in the visualization of all coronary artery branches with high sensitivity and specificity achieved [29,30]. Although the multisegment or multiphase reconstruction approach increases temporal resolution, the effectiveness of these algorithms depends on the relationship between heart rate, gantry rotation time and pitch [31]. Although image quality has been shown to improve with the use of multisegment reconstruction, diagnostic accuracy was not affected [32].

The improvements in cardiac CT imaging led to the development of even faster CT scanners. Dual-source CT (DSCT) was designed to improve temporal resolution to 75 ms, thus increasing image quality by reducing motion artifacts and eliminating the need to control the heart rate during the scan [33,34]. Studies have shown that cardiac CT image quality of the coronary artery is independent of heart rate with DSCT (Figure 2) [35,36], so this indicates a significant improvement in CCTA for the assessment of patients with a high heart rate. Table 1 summarizes the diagnostic value of CCTA based on 64-slice CT, according to a number of systematic reviews and meta-analyses.

Post-64-slice CCTA
The development of a wide area detector CT enables greater coverage per gantry rotation [37–39]. Expansion of MSCT systems from a prototype 256-slice to a 320-slice system has allowed for acquisition of whole-heart coverage in one gantry rotation with a slice thickness of 0.5 mm. This eliminates ‘stair-step’ artifacts that are observed during 64-slice CCTA scans. Full cardiac coverage with one gantry rotation allows for evaluation of coronary arteries in patients with arrhythmias, such as with atrial fibrillation. The imaging principle of 320-slice CT is different from previous generations of MSCT scanners as there
is no need to piece together image subvolumes acquired over several heartbeats (normally four to five heartbeats for 64-slice CCTA) to reconstruct the entire cardiac volume. With 320-slice CT, a 16 cm of craniocaudal coverage can be obtained in a single heartbeat to show the entire coronary arteries with excellent image quality. Initial experience using 256- and 320-slice CT in cardiac imaging is promising [39–41], although further work with the inclusion of a large cohort of patients is required to investigate the effect on image quality and diagnostic value when scanning protocols are adjusted to lower radiation and contrast doses.

Despite extended z-axis coverage with the use of 256- and 320-slice CT, temporal resolution of these scanners is still inferior to that of the second generation of DSCT scanners, which enable acquisition of 128 slices simultaneously [42,43]. This DSCT mode allows CCTA to be performed by combining high pitch value of up to 3.4 with large detector coverage, thus, the acquisition time of CCTA is reduced to a quarter of a second, allowing depiction of the entire heart within a single heartbeat.

Clinical applications of CCTA
CCTA has been increasingly used in the diagnosis of CAD and the prediction of major adverse cardiac events owing to its reduced invasiveness and improved diagnostic performance. The diagnostic accuracy of CCTA has been significantly enhanced with the development of MSCT scanners, from four-slice CT to the latest models of 256- and 320-slice CT. Similarly, the predictive outcomes of CCTA with the use of 64-, or more, slice CT scanners show promising results.

Diagnostic accuracy of CCTA
Early studies using four- and 16-slice CT showed moderate diagnostic accuracy in the diagnosis of CAD due to technical limitations [44]. Image quality of coronary artery visualization was impaired and suboptimal in a number of cases with four-slice CT as the unassessable coronary segments could be as high as (more than) 33% [18,44]. With 16-slice CT, thinner detector rows increased the spatial resolution and further shortened the total scan time. Therefore, image quality in 16-slice CT angiography has become more consistent with the reported sensitivities and specificities, ranging from 83 to 98% and 96 to 98%, respectively [19,21,22,45]. Further increased diagnostic accuracy was achieved with 64-slice CT due to improved spatial and temporal resolution, thus leading to shorter examination times. Several meta-analyses of 64-slice CT studies in the diagnosis of CAD reported that the sensitivities were more than 90% and specificities more than 96% in most of the studies [1–5].

Heart rate control with the use of β-blockers is necessary in 64-slice CCTA as image quality is affected by motion artifacts in patients with heart rates over 65 beats per minute. This limitation has been overcome...
by the introduction of DSCT as the temporal resolution was increased from 165 to 75 ms, thus image quality and diagnostic value of CCTA was less dependent on heart rates. In their meta-analysis, Salavati et al. reported that only 8% of the total number of patients undergoing DSCT coronary angiography received β-blockers [46], and this is significantly lower than the 41–76% of patients undergoing 64-slice CCTA that received β-blockers [1,4]. Apart from β-blockers, ivabradine can also be used as an alternative to reduce heart rate. Oral ivabradine has been reported to be a safe and effective heart rate-lowering agent when compared with β-blockers, according to a recent study [47]. Despite a wide range of different heart rates being included in CCTA, DSCT coronary angiography shows improved diagnostic performance [48,49].

Results using 320-slice CCTA compare favorably with the studies using 64-slice and DSCT coronary angiography [39–41,50–52]. In their recent study, van Velzen et al. reported a sensitivity and specificity of 100 and 85%, respectively, for 320-slice CCTA in 106 patients with acute chest pain admitted to the emergency department [50]. Pelliccia et al., in their prospective study consisting of 118 unselected consecutive patients with suspected CAD, demonstrated the excellent results with 320-slice CT, with more than 90% sensitivity, specificity, positive predictive value and negative predictive value achieved at the per-patient, per-vessel and per-segment analysis [51]. These results indicate that 320-slice CT has the potential to broaden the use of CCTA to more patients, such as patients with atrial fibrillation.

In summary, the sensitivity of CCTA has been significantly improved with 64- or more, slice CT scanners when compared with the early generations of 4- and 16-slice scanners; however,
the specificity and negative predictive value remain consistently high (>90%), regardless of the type of CT scanners. This indicates that the main role of CCTA is to rule out significant CAD, thus reducing the need for invasive coronary angiography. The prime indication of CCTA is to diagnose patients with a low and intermediate probability of CAD as a simple noninvasive imaging test, while patients with a high probability of CAD will benefit from invasive coronary angiography.

■ Diagnostic value of CCTA: effect of coronary artery calcium score
The diagnostic performance of CCTA may be limited due to the presence of severe calcification in the coronary lumen, yielding false-positive results. Several studies performed with 64-slice CT have demonstrated that vessel calcification is a serious limitation to the specificity in patients with a coronary calcium score above 400 [52–54]. However, the current literature shows that there is controversial evidence as to whether the coronary calcium score should be used as a reference for recommending CCTA [55,56]. den Dekker et al., in their recent systematic review and meta-analysis, concluded that with 64-slice and new CT scanners, CCTA has high sensitivity and specificity for diagnosis of significant CAD in the presence of severe calcification, thus, a coronary calcium score cutoff for performing CCTA is no longer indicated [56].

■ Prognostic value of CCTA
The anatomy-based approach is a well-established method for risk stratification of patients as demonstrated by invasive coronary angiography, which clearly delineates the severity and extent of significant coronary stenosis. High risk coronary anatomy (three-vessel CAD, stenosis of left main coronary artery) is directly related to poorer outcomes [57–59], while a normal coronary artery is associated with an excellent prognosis [60]. The coronary calcium score has demonstrated incremental prognostic value over traditional risk factors, with a sevenfold increase in the incidence of cardiac events for Agatston scores >100 when compared with patients with a zero calcium score [61,62]. Despite many reports showing the prognostic value of coronary calcifications detected on nonenhanced CT scans, it was not until very recently that the prognostic value of CCTA has been made clear.

Early studies investigating the short- to midterm outcomes of patients undergoing 64-slice CT angiography reported that CCTA is able to provide independent prognostic information for predicting cardiac events and mortality in patients with known or suspected CAD [63,64]. Findings of CCTA based on a single center

| Table 1. Systematic review and meta-analysis of coronary computed tomography angiography in the diagnosis of coronary artery disease. |
|------|----------------|----------------|----------------|
| Study (year) | Articles included in the analysis (studies), n | Pooled patient-based sensitivity, specificity, PPV and NPV (%) | Pooled vessel/segment-based sensitivity, specificity, PPV and NPV (%) |
| 64-slice coronary CT angiography | 64-slice coronary CT angiography | 64-slice coronary CT angiography | 64-slice coronary CT angiography |
| Abdulla et al. (2007) | 18 | 97.5, 91, 93.5 and 96.5 | Segment-based: 86, 96, 83 and 96.5 | [3] |
| Sun et al. (2008) | 15 | 97, 88, 94 and 95 | Vessel-based: 92, 92, 78 and 98 | Segment-based: 90, 96, 75 and 98 | [1] |
| Vanhoenacker et al. (2007) | 6 | 99 and 93† | Vessel-based: 95 and 93† | Segment-based: 93 and 96† | [2] |
| Prospective ECG-triggered coronary CT angiography | Prospective ECG-triggered coronary CT angiography | Prospective ECG-triggered coronary CT angiography | Prospective ECG-triggered coronary CT angiography |
| Sun et al. | 14 | 99, 91, 94 and 99 | Vessel-based: 95, 95, 88 and 98 | Segment-based: 92, 97, 84 and 99 | [96] |
| von Ballmoos et al. | 16 | 100 and 89† | Vessel-based: 97 and 93† | Segment-based: 91 and 96† | [95] |

†Indicates PPV and NPV were not provided in these studies.
CT: Computed tomography; NPV: Negative predictive value; PPV: Positive predictive value.
experience have been closely associated with future cardiac events, with 0 or 1% of cardiac events being reported in patients with normal cardiac CT or mild coronary artery disease, and up to 30% in patients with one or more vessel obstructive CAD [65,66]. Recently, two meta-analyses of studies on the prognostic value of CCTA showed that cumulative major adverse cardiac events with a mean follow-up of 20–21 months ranged from 0.17 to 0.5% in patients with normal CCTA findings, 1.4–3.5% in those with nonobstructive CAD and 8.8–16.0% in patients with obstructive CAD by 16- and 64-slice CT angiography [7,67]. Compared with a normal CCTA, nonobstructive CAD was associated with a significantly increased risk of major adverse cardiac events, while obstructive CAD was associated with a greatly increased further significant risk. The presence and extent of nonobstructive plaques have been reported to enhance prediction of incidental mortality beyond traditional clinical risk assessment [68,69]. The prediction of excellent prognosis together with the high negative predictive value makes CCTA the appropriate imaging modality to exclude CAD and prognosticate populations with different pretest likelihoods for CAD.

Prospective multicenter trials evaluating patients presenting to the emergency department with acute chest pain symptoms further confirmed the prognostic value of CCTA [70–72]. Incorporating CCTA into a triage strategy improved the efficiency of clinical decision-making and allowed the safe, expedited discharge from the emergency department of many patients who would otherwise be admitted [73,74]. These findings demonstrated that the presence and severity of atherosclerotic plaque on CCTA acted as independent predictors of acute coronary syndrome. Box 1 is a summary of clinical indications of CCTA in CAD.

Integration of CCTA with myocardial perfusion imaging

Although CCTA with the use of 64-, and more, slice scanners presents excellent ability to completely assess the entire coronary tree with good diagnostic accuracy in the identification of significant coronary stenosis, anatomically significant coronary stenosis is not always indicative of functional stenosis. This is particularly true for the assessment of intermediate type coronary lesions [75,76]. According to the guidelines of the European Society of Cardiology, and the American College of Cardiology/American Heart Association, the decision to perform interventional procedures, such as coronary angioplasty or bypass surgery, should integrate anatomical information with a test that provides objective proof of ischemia [77,78].

Contrast-enhanced dual-energy with DSCT has been reported to depict myocardial ischemia using the myocardial blood pool images [79,80]. Blankstein et al. reported that adenosine stress CT detected stress-induced myocardial perfusion defects with a diagnostic accuracy comparable to that of single-photon emission CT [80]. Nagao et al. recently demonstrated functional assessment of coronary artery flow using cardiac CT, with a change in coronary

<table>
<thead>
<tr>
<th>Box 1. Indications for coronary computed tomography angiography in the diagnosis of coronary artery disease.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Very low pretest probability of coronary artery disease:</strong></td>
</tr>
<tr>
<td>– Coronary computed tomography (CT) angiography is not recommended due to high radiation dose</td>
</tr>
<tr>
<td>– Traditional risk assessments (Framingham risk score for asymptomatic patients; Diamond and Forrester Method and the Duke Clinical Score for symptomatic patients)</td>
</tr>
<tr>
<td><strong>Low-to-intermediate pretest probability of coronary artery disease:</strong></td>
</tr>
<tr>
<td>– Coronary CT angiography with 64-, and more, slice scanners is recommended due to its high diagnostic value</td>
</tr>
<tr>
<td>– Detection of atherosclerosis by demonstrating coronary plaques</td>
</tr>
<tr>
<td>– Confirmation of degree of coronary stenosis and coronary arteries/segments involved</td>
</tr>
<tr>
<td>– Invasive coronary angiography can be avoided based on the high specificity and very high negative predictive value</td>
</tr>
<tr>
<td><strong>High pretest probability of coronary artery disease:</strong></td>
</tr>
<tr>
<td>– Invasive coronary angiography is recommended, as both diagnostic and therapeutic value (coronary intervention) can be achieved</td>
</tr>
<tr>
<td>– Indications for coronary CT angiography in the prediction of cardiac events</td>
</tr>
<tr>
<td>– Coronary calcium scoring to predict major adverse cardiac events</td>
</tr>
<tr>
<td>– Assessment of presence and extent of plaques (obstructive vs nonobstructive)</td>
</tr>
<tr>
<td>– Assessment of coronary artery involvement (single vessel vs multivessel disease)</td>
</tr>
<tr>
<td>– Incorporation of coronary CT angiography in patients presenting to the emergency department for risk stratification</td>
</tr>
</tbody>
</table>
artery flow under adenosine stress closely related to the physiological significance of coronary stenosis [81]. These early reports, along with a recently published study by Wang et al., indicate that dynamic stress myocardial CT perfusion imaging offers diagnostic accuracy comparable to that of single-photon emission CT for detecting myocardial perfusion defects [82]. A more comprehensive and accurate assessment of coronary stenosis and myocardial perfusion with a single modality consisting of CT perfusion and CCTA could be achieved without increasing radiation dose.

**Radiation dose associated with CCTA**

Radiation dose is becoming a major issue for CCTA, since CT is associated with a risk of cancer development. The National Academies’ Biological Effects of Ionizing Radiation 7th Report (BEIR VII Phase II) provides a framework for estimating cancer risk associated with radiation exposure from CCTA [14]. BEIR VII develops risk estimates for cancer from exposure to low-level ionizing radiation using the most current data and epidemiological models available on the health effects of radiation. According to the report, it is estimated that one in 2000 people will develop cancer due to an exposure of 10 mSv. Brenner and Hall estimated that approximately 1.5–2.0% of all cancers in the US may be caused by radiation exposure from CT examinations [12]. Therefore, CCTA should be performed with dose-saving strategies whenever possible to reduce the radiation exposure to patients.

Previous studies have reported that CCTA, with the use of retrospectively ECG-gated techniques, results in a very high effective dose, which ranged from 13.4 to 31.4 mSv [83]. A number of techniques have been introduced to reduce the radiation dose in coronary CT imaging in order to accomplish the ‘as low as reasonably achievable’ (ALARA) rule. These dose-reduction techniques include ECG-controlled tube current modulation, lower x-ray tube voltage, high pitch, prospective ECG-triggered scanning and reconstruction algorithms [6,84].

**Dose-reduction strategies**

Radiation dose in CT can be reduced significantly by applying the approach of tube current modulation. Either ECG-controlled or anatomical-dependent tube current modulation results in effective dose reduction significantly between 22 and 52%, compared with retrospective ECG-gated without any modifications [85,86]. In ECG-controlled modulation, the tube current is reduced to the level between 46 and 80% from its maximum at diastole (60–80% of R-peak to R-peak interval) [86]. A recent phantom study comparing different dose-saving techniques demonstrates a significant reduction of about 65% in effective dose with ECG-controlled tube current modulation when compared with the corresponding retrospectively ECG-gated protocol [87].

Adjusting the tube voltage, kVp according to the patient’s BMI is an effective approach to reduce radiation dose during CCTA. Early studies have shown that decreasing the x-ray tube voltage from 120 to 100 kVp or 80 kVp resulted in up to 70% reduction in radiation exposure for a constant tube current using 16- and 64-slice CT, with increased image noise and unchanged contrast-to-noise ratio [88,89]. Later reports utilizing DSCT compared a 100 kVp protocol with the routine 120 kVp for CCTA, and demonstrated a dose reduction of 25–54%, with an estimated effective dose as low as 4.4 mSv [90,91]. It should be noted that lowering tube voltage from 120 to 100 kVp is recommended when the patient’s BMI is less than 25. Reduction of the tube voltage to 80 kVp should only be considered in children and slim young adults with a BMI below 20.

Additional dose reductions can be achieved using prospective ECG-triggering or the step-and-shoot method. Prospective ECG-triggering with nonhelical scan was used a long time ago with electron-beam CT for calcium scoring; however, it has been increasingly used in recent years for CCTA, due to its resultant (very) low radiation dose. Studies performed with prospectively ECG-triggered CCTA have reported reduction of the effective dose by up to 90% when compared with the traditional approach, retrospectively ECG-gated technique, with diagnostic image quality being achieved in more than 90% of the cases [82–84]. A direct comparison of prospective ECG-triggering with retrospective ECG-gating has shown high diagnostic value (more than 90% of sensitivity and specificity) of prospectively ECG-triggered CCTA for evaluation of coronary arteries with assessable coronary segments of more than 95% [95–97]. The effective dose of prospectively ECG-triggered CCTA is comparable with, or even lower than that of invasive coronary angiography [95,96]. Thus, low radiation dose can be achieved in patients with low and regular heart rate with
prospectively ECG-triggered CCTA, regardless of the CT scanner generation. It has been reported that BMI is identified as the main factor that significantly affects the radiation dose in prospectively ECG-triggered CCTA [98].

Further dose reduction can be achieved by a combination of prospective ECG triggering with high-pitch spiral acquisition, which results in a consistent low dose [99,100]. This is only achievable with the second generation of DSCT scanners, Siemens definition Flash® (Siemens Healthcare, Forchheim, Germany), with acquisition of 128 slices per gantry rotation, and high temporal resolution of 75 ms. This DSCT mode allows CCTA to be performed at a pitch value of up to 3.4 with significant reduction of radiation dose. By combining high-pitch and large detector coverage, the acquisition time of CCTA is reduced from the previous 5–10 s to a quarter of a second, allowing depiction of the entire heart within a single heartbeat. More than 90% of all coronary segments were assessable with DSCT coronary angiography at a high pitch of 3.4, resulting in a radiation dose less than 1 mSv [99,100].

More recently, iterative image reconstruction has emerged as an exciting new tool in cardiac CT imaging, offering opportunities for dose reduction and improvements in image quality [101,102]. Clinical evaluation has shown up to 60% dose reduction compared with standard filtered back projection while maintaining diagnostic images [103]. CCTA incorporating iterative reconstruction resulted in a significant reduction in the effective dose.

Conclusion
CCTA represents the most rapidly developed imaging modality in cardiac imaging, with satisfactory results having been achieved. The technological advances in multislice CT scanners have gradually overcome the technical and diagnostic challenges, thus, these advances have led to a dramatic impact on its accuracy in diagnosing CAD and predicting major adverse cardiac events.

Radiation dose associated with CCTA has increased substantially over the last decade with the development of multislice CT scanners and widespread use of cardiac CT. This has raised a serious concern, which needs to be addressed by both clinicians and manufacturers. Various dose-saving strategies have been undertaken in the past few years to lower radiation exposure to patients undergoing CCTA, with tremendous progress having been achieved. Effective dose reduction has been accomplished by employing techniques with a radiation dose of less than 10 mSv to as low as 1 mSv in some studies. However, much effort is still required to ensure that CCTA is safely performed in imaging patients with suspected CAD. Appropriate utilization of CCTA must be defined as to whether it leads to the greatest benefit and whether the radiation risk may be greater than the benefit expected from the cardiac CT examinations.

Future perspective
Current studies have shown that CCTA has high diagnostic value in patients with suspected or known CAD. Excellent spatial resolution (isotropic voxel 0.5 × 0.5 × 0.5 mm³ or 0.6 × 0.6 × 0.6 mm³) allows a comprehensive evaluation of atherosclerotic plaques, thus, diagnostic performance and predictive value of CCTA have been consistently high, according to the recent literature. Despite improved temporal resolution with DSCT, the temporal resolution of recent models is still inferior to that of invasive coronary angiography, thus, aggressive approaches such as heart rate control are necessary in most of the studies. Future directions in CT technology will focus on the development of fast CT scanners with high temporal resolution with the aim of capturing cardiac images within a very short time, with fewer motion artifacts.

Radiation dose associated with CCTA remains a concern, given the fact that CCTA is increasingly used in daily clinical practice. Thus, development of low-dose CT scanners may potentially be another future direction. Further developments in CT scanners will enable CCTA to serve as a ‘one-stop-shop’ tool for cardiac imaging as it fulfills the requirements of being accurate, safe and ‘economically reasonable’, and having prognostic value. A simple CCTA examination provides a comprehensive analysis of coronary plaque burden, assessment of coronary disease extent and prediction of cardiac events.

Financial & competing interests disclosure
The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.

No writing assistance was utilized in the production of this manuscript.
Executive summary

Developments in coronary computed tomography angiography
- Cardiac imaging becomes realistic with high reliability due to technical improvements.
- Coronary computed tomography (CT) angiography enables accurate visualization of coronary arteries and detection of coronary plaques.

Diagnostic value of coronary CT angiography
- High with 64-, and more, slice scanners.
- Very high negative predictive value can reliably rule out obstructive coronary stenosis.

Prognostic value of coronary CT angiography
- Offers prognostic information for predicting cardiac events.
- Independent predictor of acute coronary syndrome in emergency department.

Myocardial perfusion imaging
- Dual-energy CT depicts myocardial ischemia.
- A single modality of assessing coronary stenosis and myocardial perfusion.

Radiation dose associated with coronary CT angiography & dose-reduction strategies
- High-dose radiation is a hot topic of debate.
- Dose-reduction strategies have been very effective.

References

Papers of special note have been highlighted as:
- of interest

8. Systematically analyzed the prognostic value of coronary computed tomography (CT) angiography in coronary artery disease.


57 Bell MR, Gersh BJ, Schaff HV et al. Effect of completeness of revascularization on long-term outcome of patients with three-vessel...
Coronary computed tomography angiography: an overview of clinical applications


74 Randomized study comparing the discharge of patients with possible acute coronary syndrome using coronary CT angiography versus traditional care.


100 Lell M, Marwan M, Schepis T et al. Landmark study showing the effectiveness of low-dose coronary CT angiography with use of the high-pitch protocol.

