

TECHNIQUES

# Computed Tomography Coronary Angiography: is There Any Progress?\*

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ABSTRACT

Significant improvements in technical capabilities of multislice computed tomography (MSCT) scanners over the recent years have resulted in better temporal and spatial resolution of computed tomography coronary angiography (CTCA) and a decrease of the acquisition time and reduction of the radiation dose. CTCA has been validated as having an excellent negative predictive value for ruling-out coronary artery disease (CAD) in populations with low-to-intermediate pretest probability and a high accuracy for detecting CAD in patients with atypical chest pain. It can also aid in decision-making for the clinical management of patients found to have significant coronary artery stenoses and in the follow-up these patients. The recent improvements of this technology are herein briefly overviewed.

**KEY WORDS:** *computed tomography; CT coronary angiography; coronary angiography; coronary arteries; coronary artery disease; radiation; calcium score*

INTRODUCTION

Since the advent of multi-slice computed tomography (MSCT), about 15 years ago, there has been a continuous and significant improvement of the technical capabilities of this revolutionary technique. Among many other clinical applications, this progress has resulted into an increasing role of non-invasive computed tomography (CT) coronary angiography (CTCA) in the detection of coronary artery disease (CAD).

TECHNICAL ASPECTS

The capability of high temporal resolution is crucial for minimizing the time needed for imaging data collection and, subsequently, for "freezing" the movement of coronary arteries during heart pulsation. The first generation of MSCT scanners, capable to obtain 4 slices per gantry rotation, was characterized by a temporal resolution of 400 ms, which improved to 250 ms in the 16-slices scanners, gradually to 165 ms (64-slices scanners) and 83 ms in dual-source CT scanners.

Spatial Resolution influences the quality of images and, specifically in the case of CTCA, the possibility to image the smaller distal coronary segments and evaluate the structure of the atherosclerotic plaque. From 4x1mm in the 4-slices scanners, spatial resolution was improved to 16x0.75 mm in the 16-slices machines and then to 64x0.6-0.4 mm in the scanners capable to obtain 64 or more slices.

ABBREVIATIONS

CAD = coronary artery disease  
CCS = coronary calcium score  
CT = computed tomography  
CTCA = compute tomography coronary angiography  
ECG = electrocardiogram  
ERD = effective radiation doses  
MSCT = multi-slice computed tomography  
SPECT = single-photon emission computed tomography

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Acquisition time is the time needed to complete the examination and determines directly the duration of breath-holding. It is mainly influenced by the number of series of x-ray detectors of the MSCT scanner which results in the number of anatomic slices scanned during each gantry rotation. For scanning the entire heart area during a CTCA examination, a 4-slice scanner needed almost 40 seconds (a very hard to achieve breath-holding), and a 16-slice scanner about 20 sec. Acquisition time and breath-holding duration were dramatically reduced to less than 10 sec, using MSCT scanners of 64 slices and more, and became equal to one or two heart beats with the newer 320- and 256-slices scanners.

The inevitably fast and spatially complex movement of the coronary arteries during the cardiac cycle, imposes a major problem when attempting to image them with CTCA. It is well known that the movement of the coronaries is minimized during the mid-diastolic phase of the cardiac cycle and, thus, the collection of data during that phase provides, in most cases, images of high diagnostic quality. The mid-diastolic phase is more lengthy with low heart rates, better lower than 60 beats per minute (bpm) Unfortunately, one cannot reliably predict the cardiac frequency of a person undergoing CTCA, during the acquisition time, due to the effects of breath-holding, bolus intravenous injection of the iodinated contrast medium and the stress status of the person. There are two main strategies used for data collection with CTCA, retrospective and prospective gating. When using retrospective gating, radiation is applied during the greater part of the cardiac cycle (usually from end-systole to end-diastole) and, after the completion of the scan, one can select the data from any part of this period, according to the heart rate of the person during the examination. Obviously, this results in high effective radiation doses (ERD), up to 10-15 mSv when the tube current is stable during the scanning (retrospective gating without dose modulation) and around 7-9 mSv when the tube current is automatically lowered during systole (retrospective gating with dose modulation). Usually, in patients with heart rate below 70 bpm, better results are achieved when data for image construction are selected during the mid-to-end diastolic period. In contrary, data from systolic period provide better images of the coronary arteries (and usually of the right one) in patients with higher heart rate. The most challenging situation, even for the dual-source CT scanners, is faced in patients with heart rates between 80 and 90 bpm when, in most cases, multiple data reconstructions at different points of the cardiac cycle are needed in order to achieve the best possible depiction of each coronary artery or even segment.

The second strategy of prospective gating or “step and shoot”, applies radiation only during the mid-to-end diastolic phase triggered by the electrocardiogram (ECG) and, thus, results to much lower ERD of about to 1-3 mSv. This last option can provide diagnostic images of the coronaries if the examined person’s heart rate remains low (<60 bpm) and

stable during the scanning period, which unfortunately is not the most common situation. Summarizing, the mean ERD is about 8 mSv when using retrospective gating with dose modulation and around 1.5 mSv when it is possible to apply the “step and shoot” protocol in the newest MSCT scanners.<sup>1,4</sup> Consequently, nowadays the radiation exposure during CTCA with modern MSCT scanners is lower compared to that of selective coronary angiography and nuclear medicine techniques.<sup>1,3,4</sup>

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#### CLINICAL APPLICATIONS AND DIAGNOSTIC PERFORMANCE

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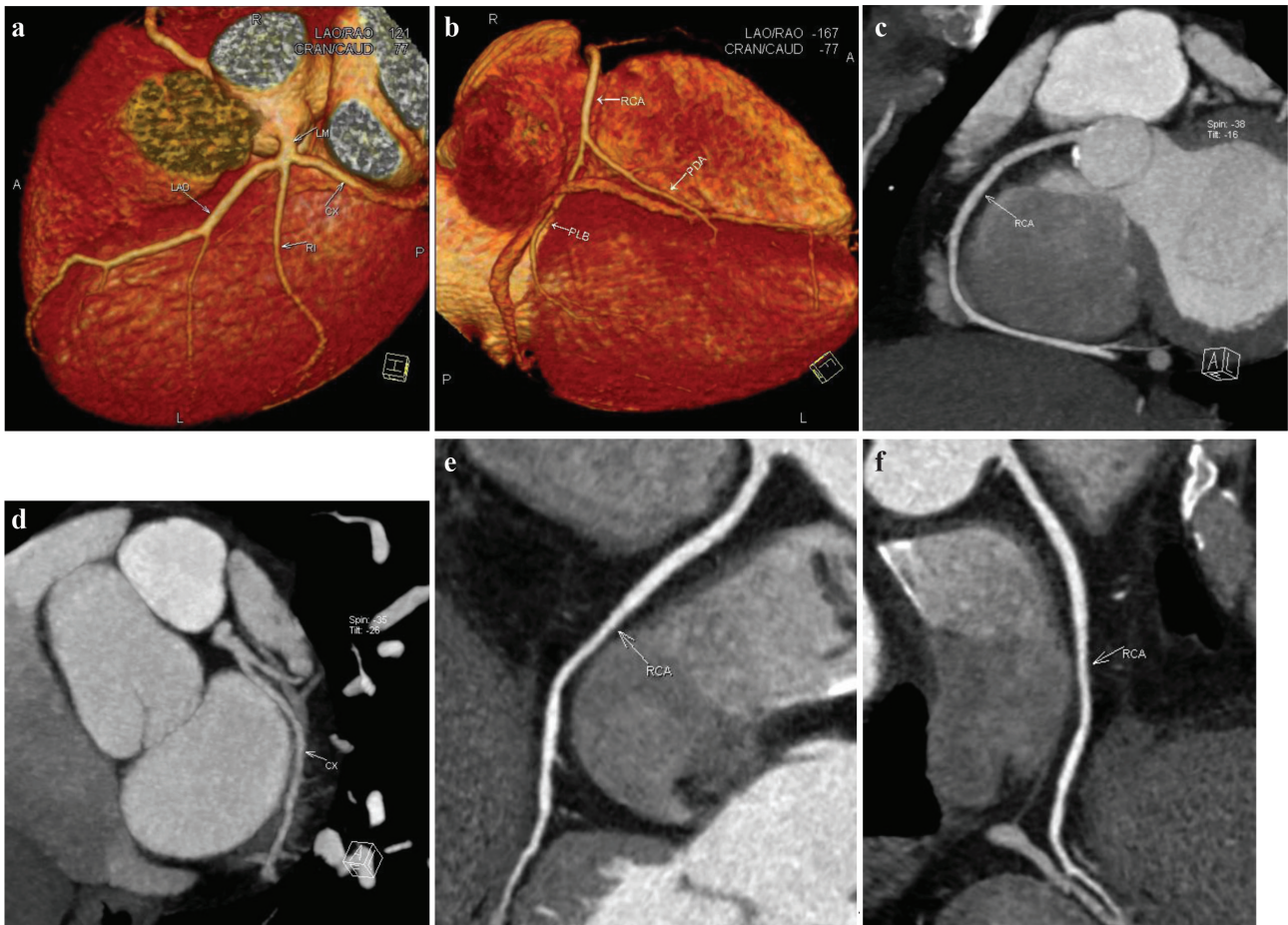
Thanks to its excellent negative predictive value, ranging between 99 and 100% and validated through many studies, CTCA is nowadays established as a very reliable test for the rule out of CAD in patients with low-to-intermediate pre-test probability (Fig. 1) Specifically, CTCA can be applied in patients with atypical chest pain who have a normal ECG and negative cardiac biomarkers, an uninterpretable or non-diagnostic ECG or equivocal cardiac biomarkers and/or are unable to undergo a stress-test (Fig. 2).<sup>5,6</sup> It can also be used for the clinical management and early triage of patients with a similar risk profile, who present with acute chest pain in the emergency room, in order to exclude the situation of an acute coronary syndrome.<sup>7,8</sup> According to the results of the ROMICAT trial, 50% of patients presenting with acute chest pain in the emergency room and having low-to-intermediate likelihood of CAD, were found to have a normal CTCA.<sup>9</sup>

For detecting significant CAD, CTCA using modern MSCT technology of 64-slices or more, was proved to have an excellent sensitivity (99-100%), and a very good specificity (86-96%) and positive predictive value (86-97%) (Fig. 3).<sup>2,10-12</sup> Beyond the detection of significant CAD, the findings of CTCA can serve as a “roadmap” for the planning of treatment procedures. CTCA can show the length of a significant stenosis or occlusion of a coronary segment, evaluate its straightness or curvature and depict any collateral vessels originating from it. All these are important criteria for deciding to attempt or not any percutaneous coronary intervention (PCI). Also, several studies have shown that the findings of CTCA have prognostic value for future cardiovascular events.<sup>13,14</sup>

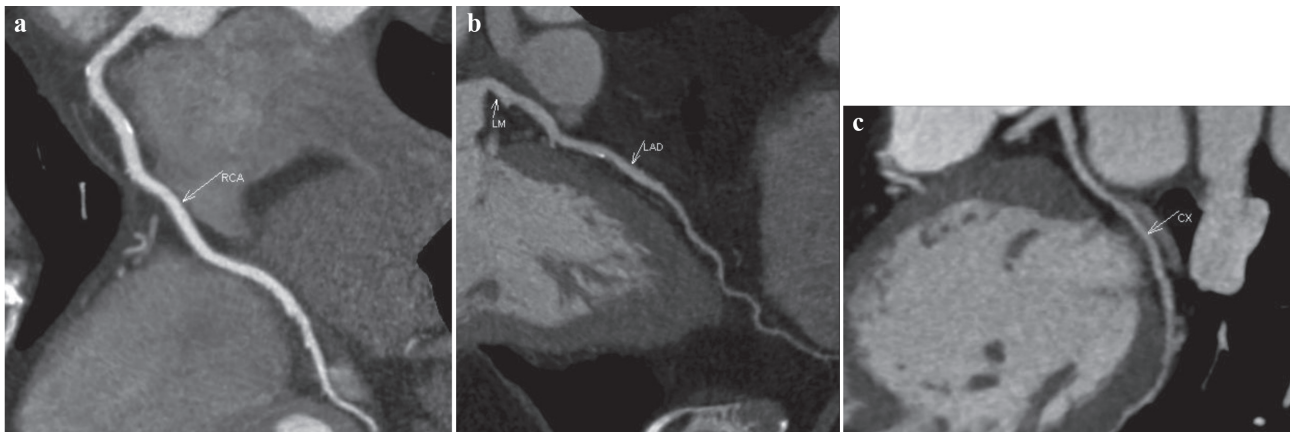
Patients with CAD treated with coronary artery by-pass grafting, can be reliably followed-up with CTCA, whenever it is clinically needed to assess the grafts’ patency. According to the results of many studies, for detecting graft stenosis >50% up to total occlusion, CTCA was found to have an excellent negative predictive value (96-100%) and very good-to-excellent sensitivity (85-100%, mean around 98%) and specificity (91-100%) (Fig. 4 & 5).<sup>15-21</sup>

CTCA is a highly accurate examination for the detection and evaluation of congenital anomalies of the coronary arteries.<sup>22</sup> Also, it is increasingly used for the evaluation of coronary

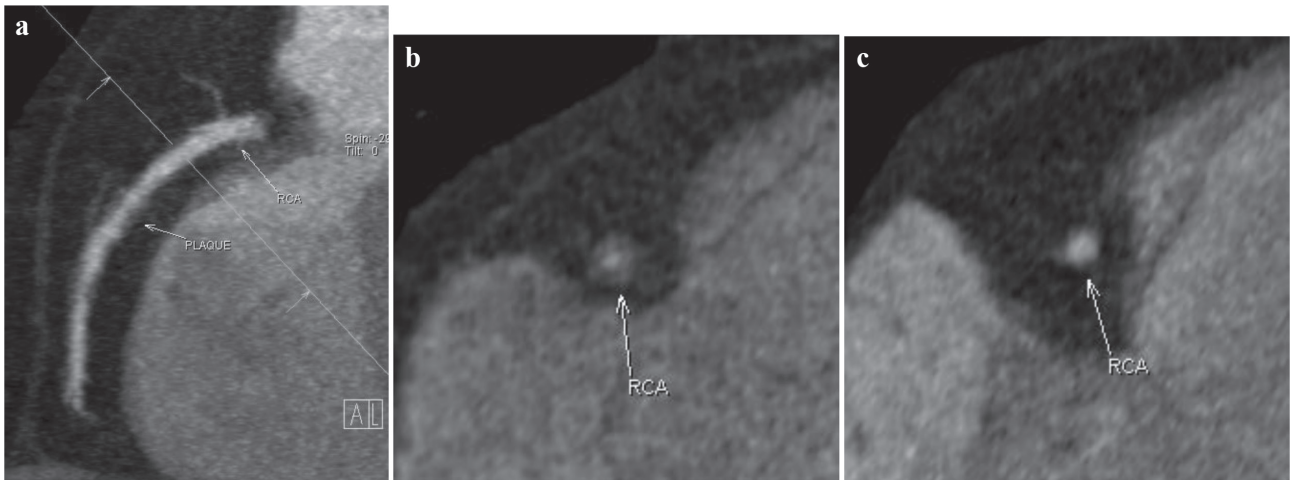
CT CORONARY ANGIOGRAPHY



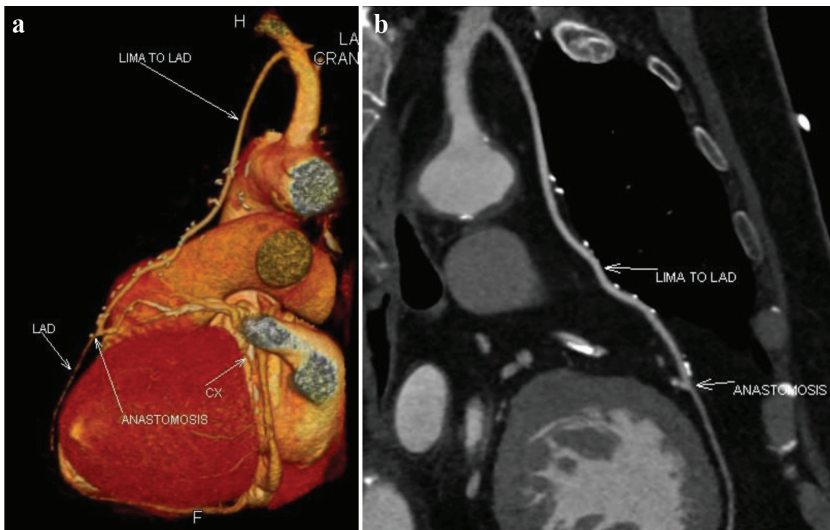
**FIGURE 1.** (a-f). Normal coronary arteries, imaged by dual-source 128-slices CTCA Three-dimensional VRT (a, b) and MIP (c, d) reconstructions, curved MPR reconstructions. CTCA = computed tomography coronary angiography; MIP = maximum intensity protection; MPR = multiplanar reconstruction; VRT = volume rendering technique.



**FIGURE 2.** (a-c). Dual-source 128-slices CTCA of a patient with atypical chest pain. Curved MPR reconstructions depict a few small eccentric calcified plaques at proximal RCA (a) and mid LAD (b), without causing any stenosis. LCx is normal (c). CTCA = computed tomography coronary angiography; LAD = left anterior descending (coronary artery); LCx = left circumflex (coronary artery); MPR = multiplanar reconstruction; RCA = right coronary artery.



**FIGURE 3.** (a-c). 64-slices CTCA of a patient with atypical chest pain. Curved MPR reconstruction of RCA (a) depicts a significant stenosis at its proximal curvature (a, arrow), due to a concentric non-calcified plaque which is nicely depicted on the orthogonal transverse reconstruction (b, arrow). For comparison, normal proximal RCA lumen and wall (a, blue line), is presented on another orthogonal transverse reconstruction (c, arrow). CTCA = computed tomography coronary angiography; MPR = multiplanar reconstruction; RCA = right coronary artery.



**FIGURE 4.** (a, b). Dual-source 128-slices CTCA of a patient with previous coronary artery bypass surgery. Three-dimensional VRT (a) and curved MPR reconstructions (b) depict very nicely a patent arterial graft of LIMA to LAD and, also, the anastomosis and the patent distal segment of LAD. CTCA = computed tomography coronary angiography; LAD = left anterior descending (coronary artery); LIMA = left internal mammary (left thoracic) artery; MPR = multiplanar reconstruction; VRT = volume rendering technique.

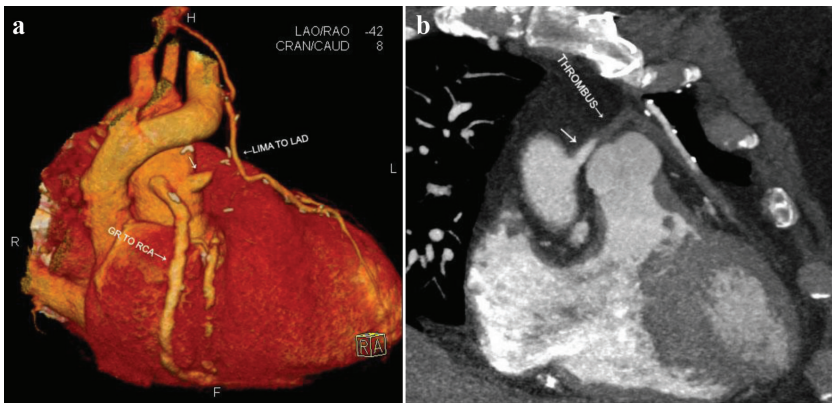
arteries in patients scheduled for non-coronary thoracic surgery (aneurysm repair, valve replacement). The most widely acceptable indications for CTCA are listed in Table 1.

### LIMITATIONS

Despite the significant technical advances incorporated into the modern MSCT scanners and the improved software tools that became available with the newest post-processing workstations, there is still a problem for accurate grading of stenoses depicted by CTCA, especially when they are caused by

heavily calcified plaques. Additionally, being a static examination, CTCA is not capable to assess the functional relevance of a significant stenosis. However, one can appreciate the unique advantage of CTCA over selective coronary angiography, in terms of being “more than a luminography” and capable of imaging the coronary wall and the positive remodelling caused by the atherosclerotic process. The clinical value of CTCA is improved when combined with single-photon emission computed tomography (SPECT) and, in the near future, with CT myocardial stress perfusion imaging.<sup>23,24</sup>

Patients with high and/or irregular heart rate represent a difficult population for CTCA.<sup>25</sup> In many situations and if



**FIGURE 5.** (a, b). Dual-source 128-slices CTCA of a patient with previous coronary artery bypass surgery. Three-dimensional VRT image (a) depicts very nicely two patent grafts: an arterial one of LIMA to LAD and a venous graft to distal RCA. A third venous graft to proximal LCx is totally occluded at its proximal part (a, arrow) due to a large thrombus that is clearly seen on a curved MPR reconstruction (b). CTCA = computed tomography coronary angiography; LAD = left anterior descending (coronary artery); LCx = left circumflex; LIMA = left internal mammary (left thoracic) artery; MPR = multiplanar reconstruction; VRT = volume rendering technique.

**TABLE 1.** Main Indications for Computed Tomography Coronary Angiography (CTCA)

- Rule out coronary artery disease in patients with low-to-intermediate clinical probability
- “Triple rule out” in patients with atypical acute chest pain\*
- Follow-up of patients with coronary artery bypass grafts
- Detection of congenital anomalies of coronary arteries
- Evaluation of coronary arteries before a major non-coronary thoracic surgery

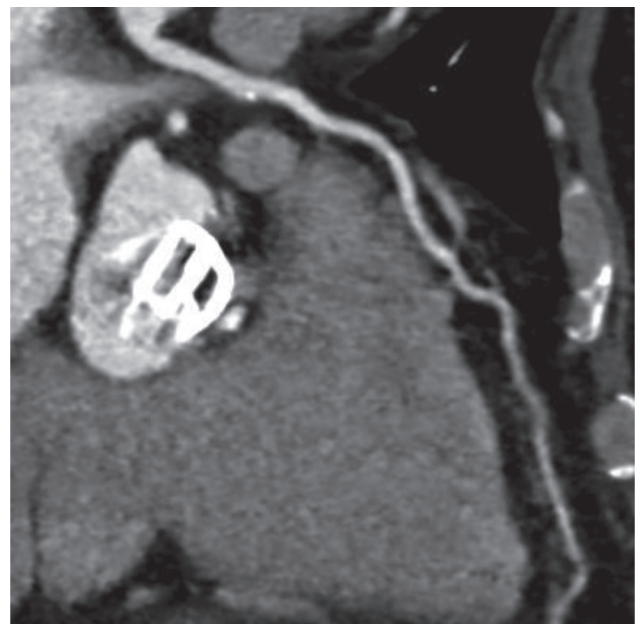
\*“triple rule-out” (covering the three main causes of chest pain): a single study (CT angiography) where you are trying to exclude the presence of *coronary artery disease* (>50% stenosis), ruling out or ruling in *aortic dissection* and the possibility of *pulmonary embolism*.

not contraindicated, beta-blockers can be safely used in order to reduce the patient’s heart rate below 65 bpm, during the examination, resulting in a reliable CTCA with reduced radiation dose.<sup>26,27</sup> However, there are patient groups where a high heart rate cannot be lowered, those with atrial fibrillation, emergency situations, children and heart transplant recipients. With the newest technology MSCT scanners and by using imaging protocols and post-processing strategies adapted to each patient’s case, it is possible to achieve a diagnostic CTCA in most patients with atrial fibrillation (Fig. 6).<sup>28</sup>

Patients with a very high body mass index represent a continuously growing population at risk for CAD. Imaging of their coronary arteries with CTCA remains a challenge.<sup>29</sup> Modern MSCT scanners and the application of dedicated imaging protocols can provide a reliable CTCA even in obese patients, at the expense of a higher radiation dose.

As previously mentioned, the presence of severe calcifications in atherosclerotic plaques reduces significantly the specificity, accuracy and positive predictive value of CTCA. For that reason, CTCA is currently not indicated for the

evaluation of patients with known or very probable CAD and/or high coronary calcium load. Although there are no widely accepted guidelines, there is a common practice of performing a coronary calcium score (CCS) assessment with MSCT, before a scheduled CTCA, in individuals with more than two risk factors for CAD and in all male individuals more than 60 years-old. According to this strategy, individuals with CCS lower than 1000 (others propose a threshold of 400) and with-

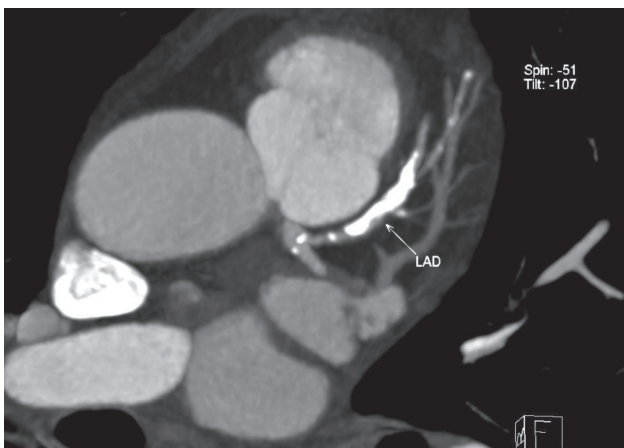


**FIGURE 6.** Dual-source 128-slices CTCA, curved MPR reconstruction of LAD in a patient with atrial fibrillation. Despite the tachyarrhythmia (32-85 bpm recorded during the examination), the LAD is nicely depicted, only with minor motion artifacts at its distal segment. CTCA = computed tomography coronary angiography; LAD = left anterior descending (coronary artery); MPR = multiplanar reconstruction.

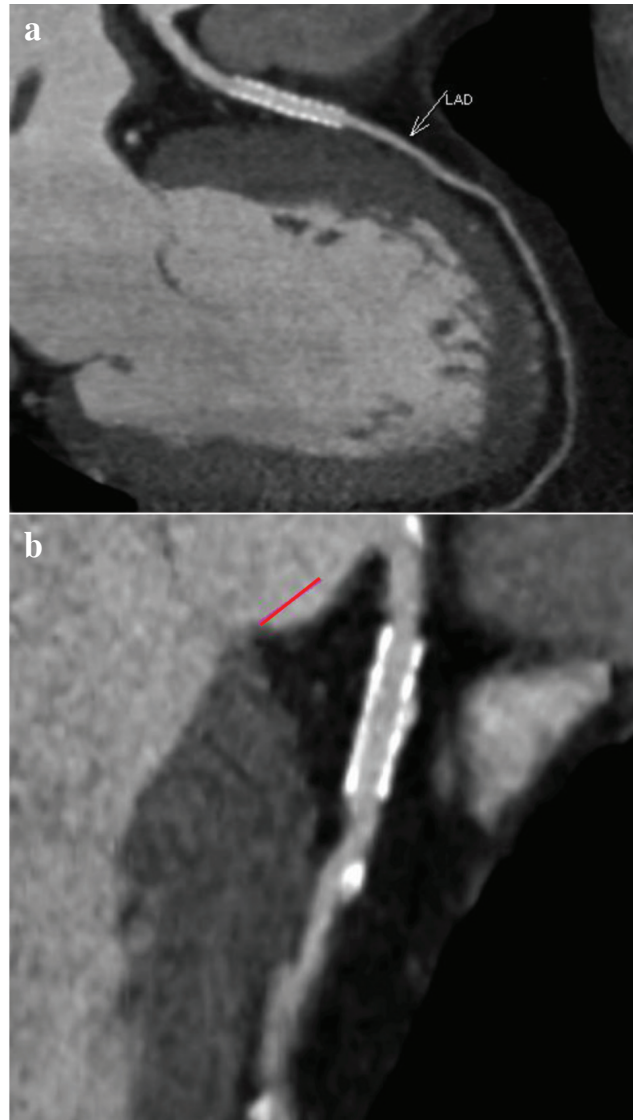
out massive accumulation of calcium on any proximal or mid coronary segment, can proceed to a most probable reliable CTCA, while those with a CCS above that threshold would better avoid a possibly inaccurate examination (Fig. 7).

Evaluation of a coronary stent patency is not an established indication for CTCA, according to the results of several studies which have shown a variable diagnostic performance depending on the stent type (size and metal content). According to a meta-analysis that evaluated the results of 14 studies, for the diagnosis of significant (>50%) stenosis of assessable stents, CTCA had a pooled sensitivity of 0.90 (0.86-0.94) and a pooled specificity of 0.91 (0.90-0.93).<sup>30</sup> Stents with a diameter >3.5 mm were found to be assessable by CTCA in 78-100% of the cases, those measuring 3 mm were assessable in 58-100%, but those sized <3 mm were assessable in 8-78%.<sup>31</sup> The stent's structure is another important factor influencing its evaluation. CTCA has a better performance in polymer stents and metal stents made from stainless steel or cobalt-chromium. Its performance is worst in bare-metal stents (containing tantalum, titanium, NIR gold-coated) and in overlapping stents.<sup>32</sup> The performance of CTCA for evaluating stents may improve by applying some changes in the imaging protocol (contrast medium with higher iodine concentration, high kVp with prospective triggering) and post-processing (different reconstruction filter, adequate window, iterative reconstruction algorithm). According to the latest version of appropriateness criteria for cardiac CT, the use of CTCA is considered appropriate for the assessment of unprotected left main coronary artery stents and stents >3 mm in asymptomatic patients, uncertain in symptomatic

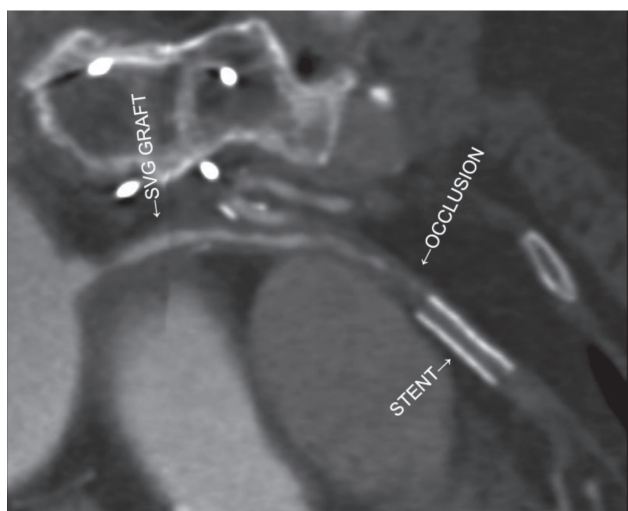
patients with stents >3 mm, and inappropriate in symptomatic patients with stents <3 mm or of unknown size.<sup>5</sup> According to another very recently published guideline, CTCA may be appropriate in any symptomatic patient with coronary stent and in asymptomatic patients with an unprotected left main stent, but in all other cases of patients with stents is considered as rarely appropriate (Fig. 8 & 9).<sup>33</sup>



**FIGURE 7.** Dual-source 128-slices CTCA, MIP reconstruction of LM and proximal LAD. The presence of heavy calcification along the proximal part of the artery, precludes the evaluation of its lumen with CTCA. CTCA = computed tomography coronary angiography; LAD = left anterior descending (coronary artery); LM = left main (coronary artery); MIP = maximum intensity protection.



**FIGURE 8.** (a, b). Dual-source 128-slices CTCA of two different patients with stents in proximal LAD (a) and proximal RCA (b). On these curved MPR reconstructions, both stents are shown to be patent and without any sign of in-stent restenosis. CTCA = computed tomography coronary angiography; LAD = left anterior descending (coronary artery); MPR = multiplanar reconstruction; RCA = right coronary artery.



**FIGURE 9.** Dual-source 128-slices CTCA, curved MPR reconstruction of a venous graft with an implanted stent. There is total occlusion of the stent and, also, of the proximal part of the graft. CTCA = computed tomography coronary angiography; MPR = multiplanar reconstruction.

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#### FUTURE PERSPECTIVE

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It is expected that the evolving technological progress will soon result in faster MSCT scanners, with more detectors, which will overcome the current limitations of this modality and expand the applications and indications for CTCA, including more detailed plaque imaging. Detectors of newer technology are expected to reduce the noise caused by heavy calcification and the metal content of some stents, and help expand the clinical applications of CTCA.<sup>34</sup> Ultra-low-dose CTCA, of less than 1 mSv, seems to be feasible in patients with a sinus rhythm and heart rate lower than 65 bpm, by using MSCT scanners of the latest generation and specific imaging and reconstruction protocols. However, its accuracy is not yet widely validated.<sup>35</sup> Even more, there is evidence that the radiation exposure during CTCA can be lowered down to that of a chest x-ray.<sup>36</sup>

Evaluation of the atherosclerotic plaque structure and detection of the vulnerable plaque are a major challenge for non-invasive coronary imaging. This aim still remains a research field, despite the continuous technological improvements of MSCT. It is estimated that magnetic resonance imaging has a higher potential on that issue, thanks to its better inherent contrast resolution.

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#### CONCLUSION

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Significant improvements in technical capabilities of

MSCT scanners during the last few years, resulted in better temporal and spatial resolution of CTCA, decrease of the acquisition time and reduction of radiation dose. CTCA is widely validated as having an excellent negative predictive value for ruling-out CAD in populations with low-to-intermediate pre-test probability and a high accuracy for detecting CAD in patients with atypical chest pain. It can also serve as a decision-making tool regarding the clinical management of patients found to have significant coronary artery stenoses and, further, to follow-up these patients after treatment. The continuous technical improvements of MSCT technology may permit, in the near future, reliable plaque imaging, more accurate grading of stenoses, integrated cardiac imaging and possibly follow-up of patients with known CAD.

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