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Can CT angiography replace catheter coronary angiography?

Koen Nieman*, MD, PhD

Departments of Cardiology and Radiology, Erasmus Medical Center, Thoraxcenter, Rotterdam, The Netherlands

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KEYWORDS

CT angiography, percutaneous interventions, invasive angiography

Abstract

After a decade of rapid technological development cardiac CT has evolved into a valuable non-invasive coronary imaging technique, which raises the question whether this new diagnostic modality is ready to replace diagnostic catheter angiography. CT coronary angiography may not yet match the spatial and temporal resolution of selective X-ray angiography, it surpasses invasive angiography in terms of three-dimensional orientation, imaging of plaque and ostial abnormalities. For the moment invasive angiography combined with stress testing will remain the preferred approach in patients with a high probability of coronary disease and anticipated percutaneous intervention. However, for many patients with a low to intermediate likelihood of coronary artery disease, CT can be a reliably non-invasive alternative to catheter angiography.

* Corresponding author: Departments of Cardiology and Radiology, Erasmus Medical Center, Thoraxcenter Bd 116, Rotterdam, The Netherlands
E-mail: Koennieman@hotmail.com

Introduction

Over the past decade cardiac CT has evolved from a technically and practically challenging procedure with unpredictable results, into a robust technique that can provide high-resolution, motion-free images of the small coronary arteries, and more. Merely a decade ago for the first time mechanical four-detector spiral CT demonstrated its ability to image the coronary arteries. Despite limitations in temporal and spatial resolution, as well as a long scan time of up to 40 seconds, this technique was able to non-invasively image obstructive coronary artery disease[1]. However, at that stage a significant proportion of examinations was not completely interpretable due to inadequate image quality. From there innovations in terms of scanner hardware, reconstruction and post-processing software, as well as clinical experience (heart rate modulation) followed at astonishing speed. Contemporary scanners acquire images at a temporal resolution of merely 150 ms, or as low as 75 ms using dual-source technology. The number of detector rows, and thereby the number of slices that can be acquired simultaneously, has grown exponentially, which reduced the total scan time to merely a few seconds. High-pitch scan modes or 320-detector-row scanners even allow scanning of the entire heart within the time of a single heart beat. Developments in computer performance, reconstruction algorithms and image processing have further advanced the speed, reliability and convenience of CT coronary angiography in clinical practice. Until 64-slice CT, improvements in image quality were achieved often at the expense of an increased radiation dose to the patient. Ultimately, concerns about radiation exposure led to various innovations to reduce the dose without sacrificing the diagnostic image quality. Examples of dose reducing techniques are low-kV scanning, ECG-triggered tube modulation for spiral scan protocols, a reintroduction of sequential step-and-shoot scan modes and high-pitch spiral scan modes. Using these applications the average dose can be well below 5 mSv, and even below 1 mSv in selected patients[2]. The current state of technology permits high-quality imaging with diagnostic results in nearly all patients, as a result of which cardiac CT has become an important diagnostic tool at an ever increasing number of medical centres around the world (Figure 1). Hence the question: Is cardiac CT ready to replace invasive coronary angiography?

Practical advantages, safety and cost of CT coronary angiography

The obvious advantage of CT as opposed to catheter angiography is its non-invasive nature. Although severe complications and death fortunately are very rare, vascular access site complications are not. CT on the other hand can be performed on an ambulatory basis without need for hospital observation. Potentially nephrotoxic contrast media and ionising radiation are drawbacks that both techniques share. However, the dose involved with cardiac CT has decreased dramatically over the past few years. Using contemporary scan techniques such as low kV tube settings, prospective ECG-triggered and high-pitch scan modes, the examination can now be performed at only a fraction of the radiation dose involved with invasive coronary angiography. Because cardiac catheterisation requires more time, more personnel, and longer observation, the cost per examination is substantially higher.

Is CT accurate enough?

Thus far the diagnostic performance of CT has been measured against invasive angiography. Numerous validation studies have demonstrated that 64-slice CT and beyond can (qualitatively) detect

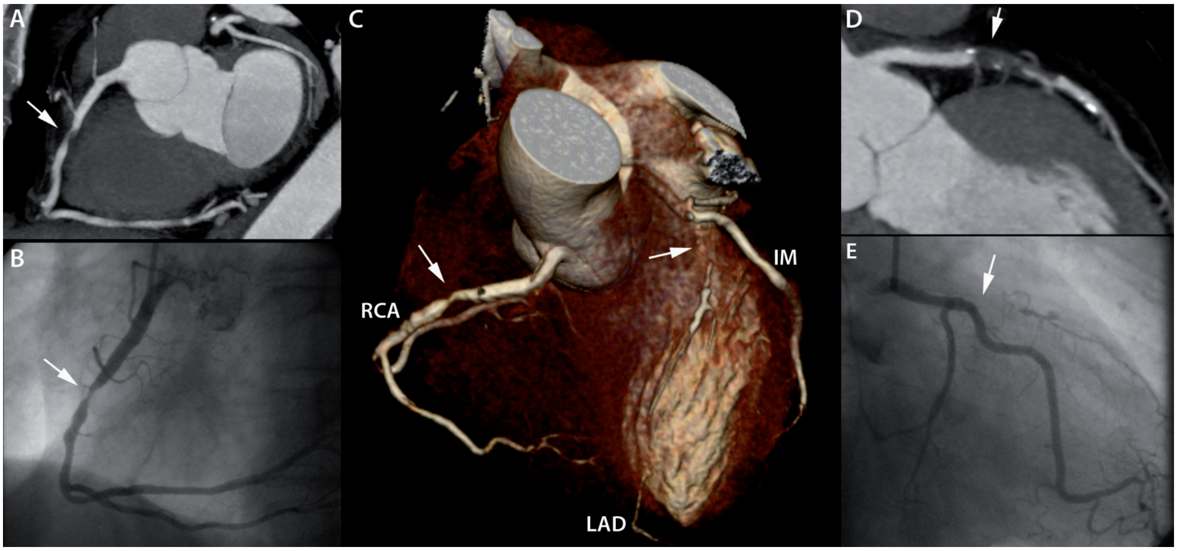

Figure 1. CT coronary angiogram. CT and catheter angiography in a patient with severe two-vessel disease. A severely obstructive, non-calcified lesion (arrow) can be identified in the mid-segment of the right coronary artery (Panels A, B, C). The left anterior descending coronary artery (LAD) is completely occluded (arrow) with collateral filling of the distal vessel via the marginal branch (MB) of the left circumflex branch (Panels C, D, E). In addition, non-calcified plaque can be observed along the cranial wall of the left main coronary artery towards the occluded LAD (Panel D). Finally, CT provides useful information regarding the amount of calcium within the occlusion, the presence of calcification at the proximal side, the location of small side branches, including a small septal branch at the proximal side, the relatively short length of the occluded segment, the extent of disease distal to the occlusion (Panel D), should percutaneous intervention of the LAD be anticipated.

obstructive coronary artery disease of the major coronary branches with high sensitivity (99%), and more than reasonable specificity (89%), on a per-patient basis[3]. The tendency to overestimate obstruction severity by CT (blooming effect by calcified lesions), as well as its readers (in an effort not to miss lesions), the positive predictive value of CT coronary angiography is modest in some studies: 93%, range 64-100% (Table 1). However, when the coronary arteries look normal on CT, they usually are, as illustrated by the excellent negative predictive value of 100%, ranging between 89-100%[3]. Quantitative stenosis severity assessment by CT and invasive angiography show good correlation, albeit with a fair degree of variation[4]. Excellent spatial and temporal resolution are among the several fundamental explanations for the superior image quality and diagnostic accuracy of invasive angiography. But without meaning to deny its status as the “gold standard” for *in vivo* coronary lumenography, it is worthwhile to consider some of the limitations of catheter-based coronary angiography. Reproducibility of (visual) stenosis severity estimations are modest and comparisons between catheter angiography and pathology demonstrated a more than negligible discrepancy[5,6]. As a projectional imaging technique conventional angiography is vulnerable to suboptimal projection angulation, vessel overlap and underestimation of the severity of asymmetric stenoses. While this problem may be mitigated by the acquisition of projections from multiple angles, some have argued that cross-sectional vessel imaging by intravascular ultrasound may be more accurate than angiography. Needless to say that CT coronary angiography will never outperform catheter angiography as long as the latter remains the reference by which it is measured. But then again, how important is perfect lumenographic accuracy? The decision to mechanically treat a coronary lesion appears better guided by its haemodynamical consequences rather than the degree of lumen encroachment[7]. The less than perfect correlation between stenosis severity and myocardial ischaemia or fractional flow reserve is well known, and similar for invasive and non-invasive coronary angiography[8,9]. Although further improvement of imaging performance is always welcome, more accurate stenosis quantification in comparison to invasive angiography may not necessarily advance the clinical utility of CT coronary angiography. As a result of the advances in risk reduction by pharmaceutical means, functional information has become ever more important for clinical decision making. Unless coronary obstruction is absent, mild or severe, (non-invasive) anatomical imaging alone will often be insufficient to guide the therapeutic management. There are several options to complement the anatomical information provided by CT. A separate stress test may be performed to assess the presence of provocable myocardial ischaemia, in patients with (suspected) obstructive disease on CT. Alternatively, CT coronary angiography and stress myocardial perfusion imaging can be assessed in the same session using a hybrid CT-PET or CT-SPECT system. More recently, the potential of stress CT myocardial perfusion imaging has been revisited. Using adenosine to induce vasodilatation, relative myocardial hypoperfusion can be identified on CT as regions of hypo-enhancement after injection of roentgen contrast medium. Preliminary comparisons between stress CT myocardial perfusion imaging and nuclear techniques show promising results[10].

How CT outperforms invasive angiography?

Probably not in overall, but certainly in some aspects, CT outperforms catheter angiography. Contrary to X-ray angiography, which as mentioned creates a shadow image of the contrast-filled coronary lumen, computed tomography provides cross-sectional images of all contrast-enhanced structures, as well as non-enhanced structures in and around the heart. Therefore, CT is better suited to demonstrate the three-dimensional morphology of the coronary arteries, and their relation with surrounding structures (Figures 1, 2). This can be particularly helpful in patients with coronary anomalies and bypass grafts (Figure 3). Unrestricted by

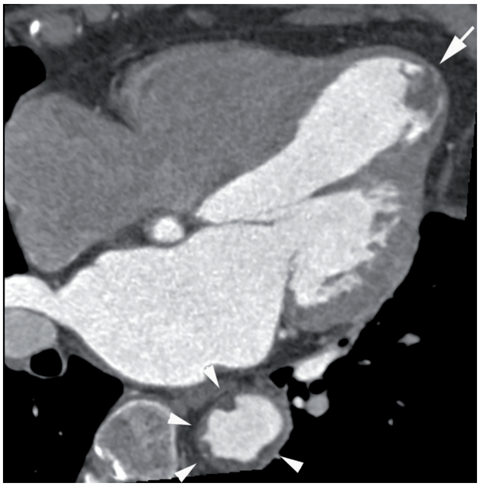

Figure 2. LV thrombus. Patient with a prior myocardial infarction and aneurysm formation of the left ventricular apex, which also contains a thrombus (arrow). Advanced atherosclerotic disease of the descending aortic wall (arrow heads).

Table 1. Diagnostic performance of 64 slice CT vs. catheter angiography.

Analysis	N	Sensitivity (pooled, CI)	Specificity (pooled, CI)	Positive PV (median, range)	Negative PV (median, range)
Per segment	14.199	90% (85-94%)	97% (95-98%)	76% (44-93%)	99% (95-100%)
Per patient	1.286	99% (97-99%)	89% (83-94%)	93% (64-100%)	100% (86-100%)

Pooled results from 18 studies comparing CT angiography with catheter angiography. PV: predictive value; CI: 95% confidence interval. Adapted from Mowatt, et al, *Heart,* 2007[3].

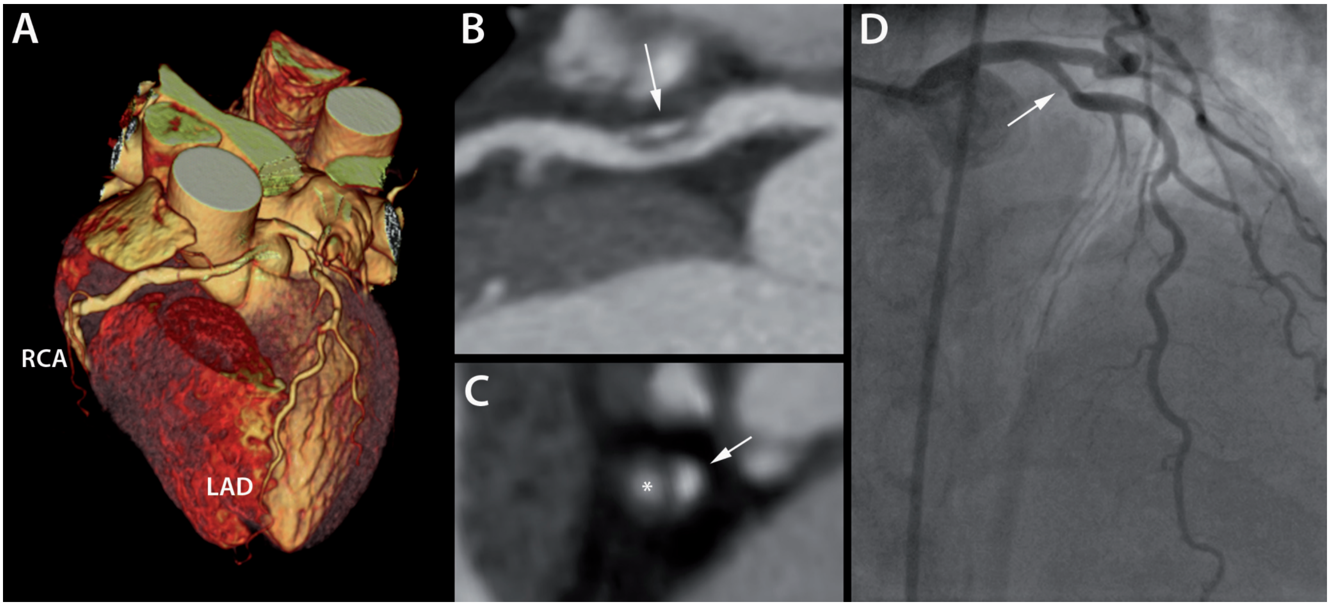

Figure 3. Anomaly and plaque imaging. An aberrant right coronary artery (RCA) originating from the left sinus of Valsalva with an inter-arterial trajectory between the common pulmonary artery and aorta (Panel A). The proximal left anterior descending coronary artery (LAD) shows a large plaque of mixed calcified and non-calcified composition (arrow, Panels B and C). Partly as a result of outward vessel remodelling, and perhaps suboptimal angulation by conventional angiography, the large plaque area in comparison to the small coronary lumen area (*), are barely noticeable on catheter angiography (Panels B, C, D).

projection angles and vessel overlap, the coronary arteries can be reconstructed and viewed from any arbitrary angle after the scan has been performed. In addition to optimal vessel alignment, cross-sectional images of the vessel similar to intravascular ultrasound can be recreated to assess obstruction severity. In addition to the coronary lumen, CT images will show the atherosclerotic vessel wall, similar albeit with lower spatial resolution to intravascular imaging techniques (Figure 3). Therefore, CT may identify coronary disease that would remain undetected on conventional angiography in the absence of lumen narrowing. Imaging coronary plaque, even in the absence of lumenal encroachment, has prognostic meaning[11], and preliminary data even suggest that CT could identify coronary plaque prone to rupture[12,13].

Finally, conventional angiography requires contrast delivered directly into the coronary artery. Apart from the potential hazards of catheter engagement, selective injection may fail in patients with anomalous coronary ostia, abnormal aortas or peripheral vascular disease, or in case of grafts that are occluded or at unexpected locations.

Added perks of CT imaging

In addition to the coronary arteries, cardiac CT visualises the entire heart and part of the thoracic vasculature. Identification of an (old) myocardial infarction, pericardial effusion, aortic disease, etc., can be explanatory for the patient's complaints. Depending on the scan, protocol datasets can be reconstructed during different cardiac phases to assess the global left ventricular function, and even regional wall motion abnormities may be detected. The myocardium may show evidence of myocardial hypoperfusion as a result of myocardial infarction or severe ischaemia (Figure 4). In case of chronic myocardial infarction there may be thinning, fatty infiltration or calcification of the ventricular wall, in addition to global or regional wall motion abnormalities[14]. All of these may be identified on a CT examination performed to visualise the coronary arteries, without need for additional contrast medium injection or scanning. If the CT angiogram is followed five minutes later by a second (low-dose) scan increased contrast enhancement of infarcted or scarred myocardium may be come visible on CT[15]. Although imaging of this phenomenon of delayed wash-in and wash-out of contrast medium due to myocyte damage or fibrosis and increased interstitial space is more commonly performed by magnetic resonance imaging, CT can be an alternative in patients with contraindications to magnetic resonance imaging.

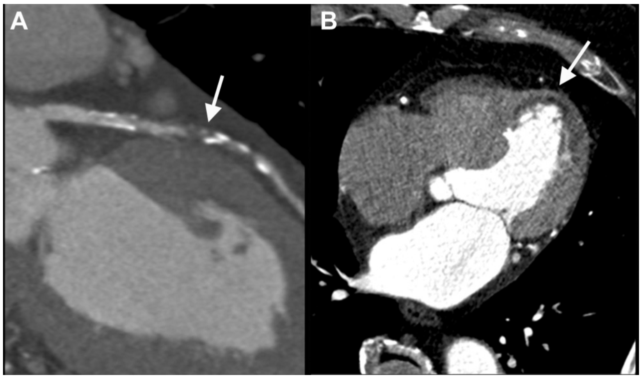

Figure 4. Myocardial contrast-enhancement. Severe obstructive disease of the left anterior descending coronary artery (arrow, Panel A) and hypo-enhancement of the dependent anterior wall of the left ventricle (arrow, Panel B), suggesting hypoperfusion as a result of severe ischaemia or prior (subendocardial) myocardial infarction.

When CT angiography can replace invasive angiography?

Answering the question whether CT can replace conventional catheter angiography depends on the purpose of the examination. Ideally invasive angiography is performed in patients with evidence of myocardial ischaemia and a high probability of obstructive coronary disease, as guidance to an anticipated revascularisation procedure. Obviously, CT cannot be followed by an intervention procedure should obstructive disease be detected. However, when obstructive coronary disease is detected during an intentionally diagnostic procedure it may be difficult not to treat those findings immediately. In this regard the inability to immediately act upon findings, with more time to assess and discuss the most appropriate therapy, may well be considered an advantage of cardiac CT. Nevertheless, CT is unlikely to replace catheter angiography as a means to plan (and perform) coronary interventions in the near future. Therefore, in patients with a high probability of coronary artery disease, preferably with evidence of myocardial ischaemia, invasive angiography is generally preferred over CT angiography[16]. Instead, the strength of CT angiography is its ability to reliably exclude coronary artery disease and avoid invasive procedures, which is more likely to happen if the pre-test probability is not high. As trends in Europe and elsewhere show, up to half of catheterisation procures is not followed by an intervention procedure (Figure 5)[17]. Among these are numerous invasive procedures in patients with low or intermediate pre-test probability. When the usual (sequence of) non-invasive stress tests turn out inconclusive, or when results remain incompatible with the clinical presentation, invasive angiography will be the decisive instrument to exclude obstructive coronary artery disease. However, in a middle-aged woman with atypical complaints and an intermediate risk stress test, or a young man with non-anginal complaints and a (miraculously) positive stress test, the chance of finding obstructive coronary artery disease is still less than 25%[18]. In these instances CT angiography could be a useful gatekeeper to invasive diagnostics.

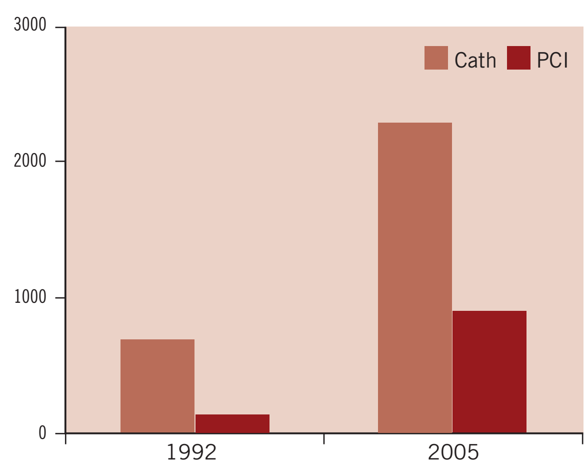

Figure 5. Invasive coronary angiography and percutaneous intervention procedures in Europe. Numbers of invasive coronary angiograms (cath) and percutaneous intervention procedures (PCI) performed in Europe in 1992 and 2005. Adapted from Praz et al[17].

Other referrals to the catheterisation lab with a relatively low probability of severe disease are those planned for valvular surgery or other major (non-cardiac) surgery, and individuals with high-risk professions (pilots, bus drivers) (Figure 6). In addition approximately 10% of unexplained heart failure is caused by unrecognised ischaemic heart disease, for which reason angiography is generally indicated. CT could be an affective means to rule coronary artery disease in this population of low probability of obstructive disease.

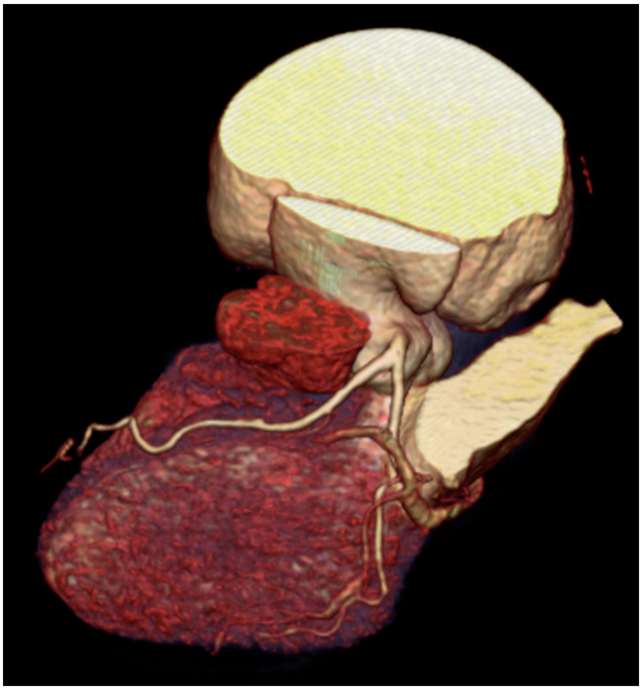

Figure 6. Dissection of the ascending aorta. Prior to postponed surgery after dissection of the ascending aorta because of neurological contra-indications, coronary artery disease was ruled out by CT coronary angiography.

Complementary use of cardiac CT

Given the previously discussed advantages of cardiac CT in terms of non-selective contrast enhancement and three-dimensional imaging of the coronary arteries and surrounding structures, CT could be of complementary use to the interventional cardiologist. Obviously CT will be of use in patients in whom selective angiography failed (anomalous coronary ostia or missing grafts) or is contra-indicated (aortic dissection, aortic valve endocarditis) (Figure 6). Also in the case of suspected ostial disease, CT may allow for better visualisation of disease severity without potential misinterpretation of induced spasm. In the preparation of bifurcation lesion treatment, unrestricted view plane angulation by CT will allow for measurement of the exact bifurcation angle as well as determination of the most optimal projection angle in the catheterisation lab, while visualisation of plaque may be helpful to anticipate plaque shifts and for instance the need for protective wiring of side branches (Figure 7). Recanalisation of coronary occlusions may benefit from CT visualisation of the occluded segment, in terms of length, tortuosity, side branches and calcium deposition.

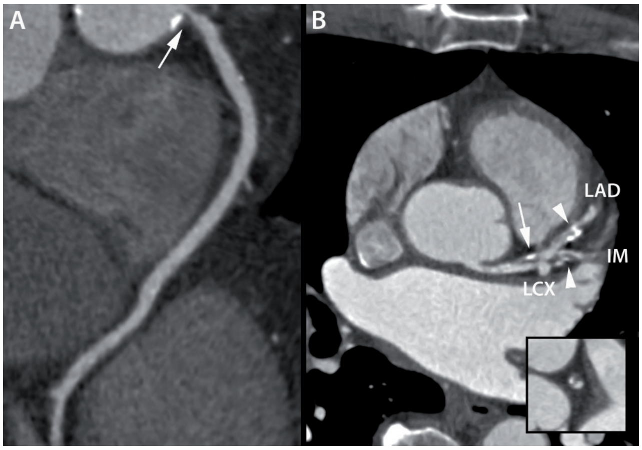

Figure 7. Complementary use of CT in the cath lab. Panel A: ostial stenosis of the right coronary artery. Panel B: diffuse atherosclerotic disease around the distal left main bifurcation, with lesions in the left main stem (arrow, cross-sectional view in the insert), the left anterior descending coronary artery (LAD) and intermediate branch (IM). CT allows optimal alignment of the left main coronary artery in an orientation difficult to reproduce in the catheterisation lab.

When should CT not replace conventional angiography?

Most importantly CT should not be performed when sufficient image quality is unlikely to be achieved. The technique remains vulnerable to artefacts in patients with a very fast and/or an irregular heart rate. In obese patients noise may be too excessive. Patients unable to lie still, hold their breath, or otherwise uncooperative are also less suitable candidates. To which extent these conditions inhibit diagnostic performance depends on the imaging question, the extent of atherosclerotic disease, as well as the available scanner technology. More detectors reduce the number of required heart cycles, thereby reducing the sensitivity to arrhythmia. Dual-source CT systems are less sensitive to faster heart rates and can deliver doubled tube output in obese patients. Interpretability is also affected by the degree of coronary disease. Some image noise and motion blurring may be permissible in an otherwise disease-free scan, while in someone with diffuse, calcified atherosclerosis only a technically perfect scan will suffice to assess lumenal obstruction. Imaging of stents also requires maximum image quality to rule out in-stent restenosis (Figure 8), and even that can be insufficient for smaller stents[19]. While graft imaging is well feasible, CT coronary angiography is often challenging after surgery because of advanced atherosclerotic disease of the native vessels[20].

Conclusion

CT coronary angiography permits convenient, non-invasive imaging of the coronary arteries, with practical advantages and added information concerning the coronary anatomy, atherosclerotic plaque and other cardiovascular conditions. Given its excellent negative predictive value, cardiac CT is most likely to replace diagnostic catheter angiography in patients with a low to intermediate probability of CAD limited to patients in whom diagnostic image quality can be achieved. In selected cases CT coronary angiography can provide complementary information to assist cardiovascular intervention procedures. In the case of a high probability of coronary artery disease, or a history of percutaneous or surgical coronary revascularisation, catheter techniques are the angiographic method of choice in most patients.

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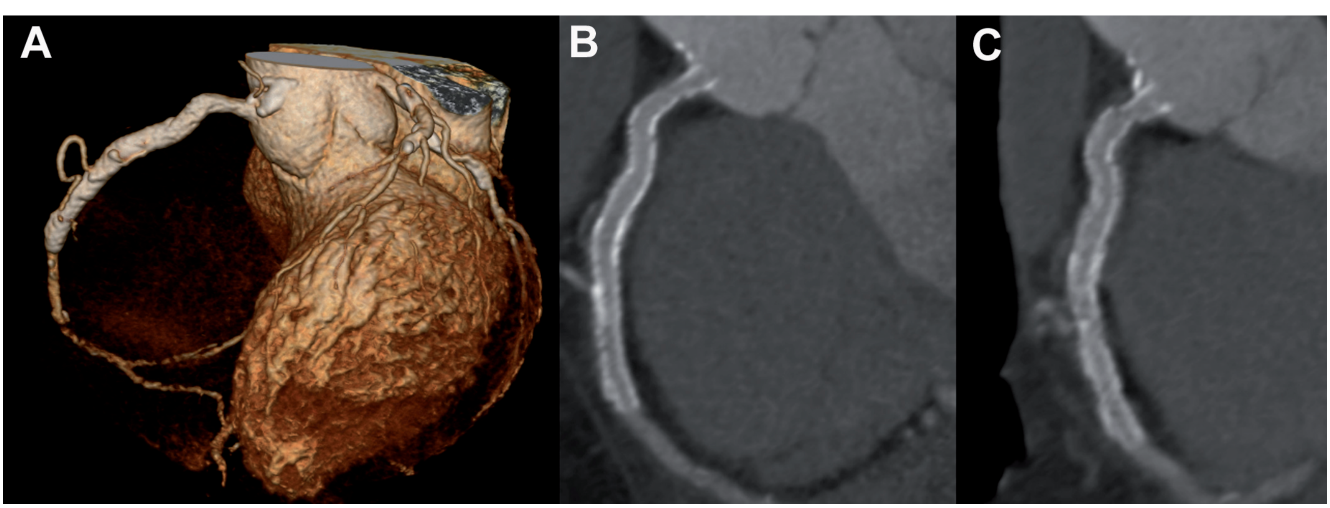

Figure 8. Stent imaging. CT angiography of a stented right coronary artery reconstructed at the most optimal cardiac phase (Panels A and B) and at a less optimal phase (Panel C) to demonstrate how insufficiently depressed motion increases blurring and beam-hardening, and renders the images not evaluable.

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