CARDIAC CT COMES OF AGE

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INTRODUCTION

Computed tomography (CT) has revolutionised medicine since its introduction as a clinical tool in the Mayo Clinic in 1972. Although the physical principles behind CT were described as early as 1917 by Radon, credit for the brilliant technical developments behind clinical CT scanning is owed to Hounsfield and Cormack, who received the Nobel Prize in 1979. New advances have allowed for electrocardiogram- (ECG-) gated images with sufficient temporal and spatial resolution to visualise the beating heart for the first time. Initially, electron beam CT (EBCT) gained popularity for the detection and quantification of coronary calcifications. The first cardiac application of multidetector CT (MDCT) followed the introduction of 4-slice scanners in the late 1990s. The evolution of MDCT technology has occurred much faster than EBCT over the last decade. Current state-of-the-art CT technology represents the seventh generation of CT scanners, and has overcome many of its previous limitations. Based on the breakthroughs of the last 18 months, CT can now perform both calcium scoring and coronary arteriography, and EBCT scanners have become obsolete. Image quality is undergoing constant refinement and the number of uninterpretable coronary studies has gradually decreased and is now as low as 3-10% with 64-slice systems.

The critical need being addressed by cardiac CT is the non-invasive diagnosis of coronary artery disease. Vascular disease is the biggest killer in Ireland today and although our ability to define risk is becoming more sophisticated with the introduction of Euroscore charts etc., our accuracy in detecting the presence of coronary disease non-invasively has been relatively poor. Multicentre studies using stress echo and nuclear stress testing still only have a sensitivity and specificity of 70-80%, even in good hands. Thus, many patients with a low risk factor profile and atypical symptoms end up with an invasive coronary angiogram. Currently, 40% of such angiograms in women in the US are normal, which suggests we need to improve our non-invasive assessment of coronary disease. Cardiac CT will answer this need.

CALCIUM SCORING

EBCT scanners have been in clinical use since the 1990s and they and current MDCT scanners are used to detect and quantify coronary artery calcifications. This gives a sense of the global burden of coronary disease, but does not reflect coronary stenosis *per se*. The most widely used measure of calcium burden is the 'calcium score', based around a radiographic density-weighted volume of plaques with pixel numbers of a least 130 Hounsfield units (HU). The prognostic value of calcification scores has been established and was a modest predictor (RR for calcium score >100 = 1.88) of hard cardiovascular outcomes (death and non-fatal myocardial infarction) at seven years follow-up. Although very high calcium scores impart an approximate 10-fold increased risk, they do not automatically imply a tight coronary stenosis. In addition, a calcium score of zero can still (but rarely) be associated with a non-calcified but tight coronary lipid-rich plaque. A high calcium score should trigger a pro-active approach to primary prevention with statins, etc., and perhaps an exercise test, but should never automatically lead to an invasive angiogram.

The role of calcium scoring of asymptomatic individuals is controversial, and the incorporation of this type of investigation into a comprehensive risk screening with C-reactive protein (CRP) and cholesterol measurements is ongoing. There is some evidence to support the incorporation of calcium scores into an overall risk stratification of older individuals using clinical algorithms such as the Framingham Risk Score. Published data support the hypothesis that a high calcium score can modify the predicted risk as defined by traditional clinical markers, especially among patients in the intermediate risk category, in whom clinical decision-making is most difficult. Those at low risk by clinical score derived no additional benefit from calcium scoring. However, the use of EBCT to improve cardiovascular risk prediction in a population with no cardiac symptoms who are at low absolute risk is very expensive. The American Heart Association has recently (October 2006) published guidelines on the issue (www.aha.org).

CT ANGIOGRAPHY

Full cardiac CT scanning with complete dataset acquisition in a six to eight second scan is now technically feasible and clinically available in Ireland. The key strength of the technology is the ability to 'rule out' coronary disease as a cause of chest pain, angina or angina equivalent (see Figure 1). Multiple studies published since mid-2005 have suggested a negative predictive value of 96-66%, which is far higher than the best non-invasive tests available up to now. In addition, cardiac CT is the best modality for imaging the rare-but-dangerous problem of coronary artery anomalies, where the origin of the vessel puts it in a vulnerable position for ischaemia and sudden death in young persons.

Patient selection is important to obtain clinically useful results. Most patients should have some form of functional or exercise test before the scan, as a truly positive exercise test with chest pain should lead straight to an invasive coronary angiogram. Older patients with heavily calcified vessels are harder to image by CT and patients in atrial fibrillation can be difficult. Obese patients often have scans with suboptimal image quality and the clinician should have a low threshold for referring on for invasive coronary angiography when the image quality is suboptimal – this is a new technology and lessons are still being learnt.

Coronary stents can 'shadow' the lumen of the vessel, especially in smaller vessels <3mm in diameter, but proximal vessel stents are relatively straightforward to visualise. Cardiac surgical bypass grafts (both vein grafts and arterial grafts), on the other hand, are much easier to accurately image, as they do not share the eccentric movement of the heart within the thorax. There are proposals to use cardiac CT as a 'one-stop shop' test for chest pain – assessing for coronary disease, pulmonary embolism (PE) and aortic dissection in a single test – but the risk-benefits of using ionising radiation in this indiscriminate manner have not been adequately studied and this is not an appropriate use of the technology at this stage. Nonetheless, despite these caveats, many patients with problematic chest symptoms are well served by cardiac CT (see Figures 2 and 3) and it can clarify an uncertain diagnosis in a way never available before (see Figure 4).

A careful review of the medical history is important prior to performing each procedure, including knowledge about prior allergy to iodine contrast, renal function, heart rate and regularity of rhythm. Adequate oral hydration is encouraged before and after performing the study. A stable, low heart rate is most important during scanning, as this determines the target point for ECG gated image reconstruction, and sometimes the target for dose modulation (to reduce radiation). We use oral (metoprolol 50-100mg) and intravenous β-blockers administered just before the study, and aim for a resting regular heart rate of <60bpm. The post-processing analysis of the images can take time and accurate interpretation relies on trained personnel with experience in the field. Unlike invasive angiography, whose images are usually very straightforward, artefacts are common in cardiac CT and take time to interpret.

Figure 1. Normal right coronary artery (RCA) by cardiac CT in a 52-year-old lady with a false positive stress test.

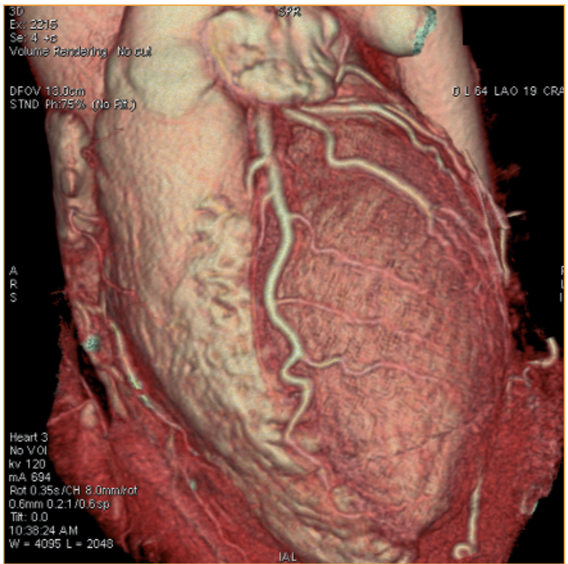

Figure 2. Normal left anterior descending artery (LAD) by cardiac CT in a non-smoking 45-year-old male with atypical chest pain.

THE DOWNSIDE

Cardiac CT, like invasive angiography, involves radiation exposure. The 'effective dose', expressed in milli-Sieverts (mSv), depends on multiple factors, including volume of acquisition required, duration of the scan and radiation energy level used. Obese individuals require larger amounts of energy due to scattering and attenuation. Current generation systems with 64 detectors provide a typical dose range in the order of 4-12mSv for CT coronary angiography. This compares to 2-6mSv for invasive angiography, 10-20mSv for nuclear stress tests involving thallium and 3.6mSv from yearly background radiation exposure in Ireland. Calcium scoring results in an effective dose of about 1.1-2.0mSv. Strategies to minimise effective dose in

MDCT include dose modulation, where the x-ray dose is stepped up in the ECG-gated target area in mid-diastole and stepped down in the rest of the cardiac cycle. This can reduce total radiation exposure up to 50% and should be used whenever possible in coronary CT. The estimated theoretical risk of cancer increases by 1:2000 CT coronary studies. Studies suggest that the longitudinal risk of cancer secondary to radiation exposure decreases with age, being significantly higher in paediatric patients and lower in older adults. Because of these concerns, the indiscriminate use of MDCT as a screening test is not warranted at the present time.

SUMMARY

Technological advances in CT in the last 18 months are bringing us close to an era of complete non-invasive diagnosis of cardiac disease. Cardiac CT is a robust reliable technology which can be used to rule out coronary disease in low and intermediate risk patients, in patients with equivocal stress tests, or in patients with normal stress tests but ongoing symptoms. While cardiac CT has great potential for replacing other diagnostic tests, practising physicians should be aware of the current limitations of this method. Image quality is sometimes suboptimal and patients must be aware that they may need invasive angiography to clarify the issue. The images obtained by CT give a true Glagovian view of the total burden of coronary atherosclerosis around and within the lumen and should not be expected to exactly mimic invasive coronary lumenography. This is a strength as well as a limitation of the technology. In addition, CT provides anatomical, not functional, information about the coronary arteries and should not be used to replace functional stress testing. Calcium scoring gives an idea of the global burden of coronary atherosclerosis, and adds a modest incremental risk. It is best reserved for intermediate risk patients needing guidance on primary prevention.

Clinical studies are also needed to determine whether diagnostic strategies that include CT angiography are cost effective and improve health outcomes. Ongoing technical research efforts will further improve spatial and temporal resolution and limit radiation dosage. Guidelines for adequate training of physicians and technical personnel have been published to regulate the widespread use of this technology. Technical advances are happening at an extraordinarily rapid rate, with the introduction of low radiation dose 'prospective ECG' scanning, dual-source scanning and myocardial perfusion scanning. While we have currently reached a plateau of development and cardiac CT has arrived as a robust new addition to diagnostic testing for heart disease, further advances are just around the corner.

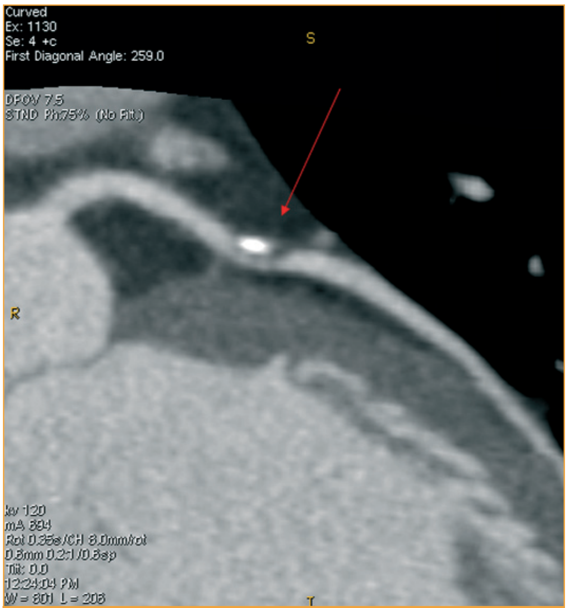

Figure 3. Severe coronary stenosis (arrow) by cardiac CT with mixed calcified (bright) and non-calcified (darker) plaque in the mid LAD of a 58-year-old smoker with ongoing chest tightness despite a normal 12-minute exercise stress test. He went on to have a successful stenting of the LAD and remains pain-free at follow-up.

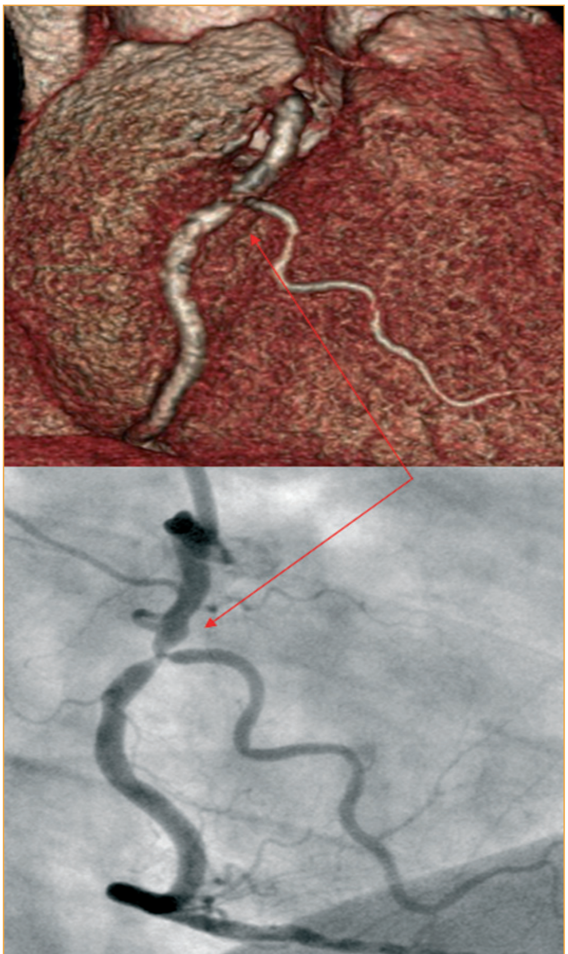

Figure 4. Tight proximal right coronary artery stenosis (arrows) by CT (above) and invasive angiography (below) in a 72-year-old diabetic with exertional shortness of breath. Implanting a coronary stent resulted in resolution of exertional symptoms.