EDITORIAL

Computed tomographic coronary angiography: how many slices do you need?

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While increasing the number of slices in multislice computed tomography clearly brings benefits in terms of detecting significant coronary disease, heavy calcification remains a problem, as does the high radiation burden

Non-invasive coronary artery imaging with multislice computed tomography (MSCT) has seen a huge expansion since the first multislice scanners were introduced in 1999. These early scanners allowed four 1 mm slices of data to be obtained in a single tube rotation of approximately 500 ms. Although this signified a major breakthrough, the resultant images were compromised by a lack of both spatial and temporal resolution. Since then there have been extraordinary technical advances with recent published data from scanners able to acquire 64 × 0.6 mm slices in a single tube rotation of just 330 ms. Has this technical progress born fruit in terms of the clinical utility of coronary CT? Are 64 slice scanners inherently better than 32 or 16 slice scanners?

A selection of studies comparing different generations of CT scanners is presented in table 1. In general terms there is an improvement in the results between four and 64 slice scanners. Simple comparison of these studies is made difficult, however, because of the wide spectrum of techniques used and differing populations studied. Comparison of the results in terms of spatial resolution, temporal resolution, scan time and radiation dose allows a more systematic approach.

SPATIAL RESOLUTION

Early results from four slice scanners demonstrated sensitivities of 72–98% and specificities of 71–98% but only with the exclusion of smaller vessels (< 2 mm) and unevaluable segments (up to 32%).[1–4] The most common reasons for vessel exclusion were motion artefacts and heavy coronary calcification. Theoretically increasing spatial resolution, with subsequent reduction in pixel size, should improve visualisation of smaller vessels and reduce artefacts from calcified coronaries. This is because of a reduction in the "partial-volume effect", in which pixels containing an area of high density such as calcium will appear white even if the majority of the pixel is lower density. The partial-volume effect exaggerates calcification and obscures the underlying vessel lumen. Reducing the pixel size (increasing resolution) should therefore minimise the detrimental effect of calcification as well as allowing assessment of smaller calibre vessels.

The results in table 1 do indeed indicate that improved spatial resolution has benefits in terms of the size of vessel that can be assessed.[1 5–14] Mollett *et al*[13] were able to evaluate all vessels of any calibre without exclusion and excellent results. This improvement is at least in part due to better spatial resolution.

The impact of spatial resolution on the detrimental effect of coronary calcification is more difficult to evaluate as the prevalence of disease, and hence calcification, varies considerably between different study populations. In this issue of *Heart*, Cordeiro *et al* specifically address this question by targeting patients anticipated to have a high calcium score, imaged with a 32 slice scanner.[14] Only subjects with advanced coronary disease on conventional coronary angiography were included (three vessel disease with at least one > 50% stenosis). A slice thickness of 0.5 mm was used, reconstructed with an overlap, giving 0.35 mm in plane resolution and isotropic voxels. As expected the calcium burden was high, with a median Agatston score of 510 and 63% of subjects having a score > 400. Vessels of less than 1.5 mm diameter were excluded. The results for detection of stenoses ⩾ 50% show a sensitivity of 76%, specificity of 94%, and positive and negative predictive values of 71% and 96%, respectively. A relatively high percentage (20%) of vessels were excluded as uninterpretable, but interestingly 65% of these were secondary to motion, noise, and/or low contrast with only 9% excluded because of calcification. This compares with a proportion excluded because of calcification of 94–100% in earlier studies.[15 16] The authors suggest that the high rate of unevaluable vessels is, at least in part, due to small vessel calibre reflecting the advanced level of disease. They also accept that the apparently limited effect of calcification compared with previous studies may reflect their tendency to under designate calcium as the cause for uninterpretability. Despite these limitations this study does provide optimism that newer generations of scanners with improved spatial resolution may be less hampered by vessel calcification. Nonetheless, other recent studies on 64 slice scanners continue to cite calcification as the most common cause of impaired image quality, accounting for all of their false positive and eight false negatives segments.[11]

TEMPORAL RESOLUTION

The second major advance of newer generation scanners is temporal resolution. This property is

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Table 1 A comparative table of multislice computed tomography (MSCT) coronary angiography

Author and year	Slice number and collimation width (mm)	Tube rotation time (ms)	Breath-hold duration (s)	Sens (%)	Spec (%)	PPV (%)	NPV (%)	Dose (mSv)	Excluded vessels size and number
Achenbach *et al* 2001[1]	4×1	500		91	84	59	98	3.9–5.8	<2 mm 32% of vessels
Nieman *et al* 2002[5]	4×1	500	25–45	84	95	67	98		<2 mm 32% of segments
Mollet *et al* 2004[6]	16×0.75	420	18.2	92	95	79	98		<2 mm
Kuettner *et al* 2004[7]	12×0.75	420		72	97	72	97	5.4–10.1	21% of segments
Mollet *et al* 2005[8]	16×0.75	375	18.9	95	98	87	99	11.8–16.3	<2 mm
Hoffman *et al* 2005[9]	16×0.75	420	16–24	95	98	85	99	8.1	<1.5 mm 6.4% of segments
Schuijf *et al* 2005[10]	16×0.5	400–600		98	97	91	99		9% of segments
Cordeiro *et al* 2006 [14]	32×0.5	400	15–22	76	94	71	96	8–18	<1.5 mm 20% of vessels
Leschka *et al* 2005[11]	64×0.6	370	<12	94	97	87	99		<1.5 mm
Raff *et al* 2005[12]	64×0.6	330		95	86	66	98	13–18	<1.5 mm 12% of segments
Mollet *et al* 2005[13]	64×0.6	330	13	99	95	76	100	15.2–21.4	None

NPV, negative predictive value; PPV, positive predictive value; Sens, sensitivity, Spec, specificity.

not specifically related to the number of detectors (synonymous with slices) but to the tube rotation time, which has fallen from 500 ms to 330 ms on the newer scanners. This is unlikely to come down much further with current spiral technology due to the physical demands of rotating a heavy *x* ray tube at high speed. At present reconstruction techniques allow a temporal resolution of as little as 83 ms, depending on the patient's heart rate.[17] This compares with 40–66 ms for conventional angiography, depending on the frame rate. The higher the heart rate the greater the need for improved temporal resolution in order to ''freeze'' coronary motion, and scanners with faster tube rotation times should cope more effectively with high heart rates.

It is difficult to separate the contribution of better temporal resolution from spatial resolution in terms of improved study results. Nieman *et al*[5] assessed the impact of heart rate on a four slice MSCT and found a significant decrease in sensitivity from 97% to 67% with heart rates of 55 and 80 beats/min, respectively. Two more recent studies have looked specifically at the effect of heart rate on image quality and suggest use of β blockers in subjects with heart rates of over 75 beats/min.[18 19] Both of these were performed on 16 slice scanners with 420 ms rotation times, and one study[19] was flawed by the comparison of very different control and patient groups. One would expect the newest generation of scanners to suffer less from motion artefact, and one of the 64 slice studies in table 1 was performed without additional β blocker.[11] Motion artefacts were seen in 24% of patients; 81% of these had heart rates > 75 beats/min but only four segments were unevaluable. This would suggest that even with moderately high heart rates, image quality on 64 slice scanners remains diagnostic. However, given the need to optimise results in the smallest vessels, most studies still use β blockers in subjects with heart rates of > 65–75 beats/min.

SCAN TIME

A major benefit of increasing the number of slices acquired and improving temporal resolution is reduction in scan time. The length of breath-hold required to perform a cardiac study on a four slice scanner was up to 45 seconds.[5] This has fallen to less than 12 seconds on 64 slice scanners.[11] In addition to allowing breathless patients to be scanned, the shorter acquisition has two less obvious advantages—reduced heart rate variability and the need for a shorter contrast bolus. The relative bradycardia at the onset of breath-holding followed by the tachycardia at the end of a long breath-hold cause a considerable variability in the R-R interval which in turn makes image reconstruction difficult.[20] Heart rate variability is reduced during a short scan making the study more robust. The need for a shorter period of coronary enhancement allows a smaller volume of contrast to be used, the benefits being reduced cost and nephrotoxic burden. The savings on contrast volume are significant, having fallen from 160 ml in early studies[21] to 80 ml in contemporary papers.[17]

RADIATION DOSE

The one major disadvantage of increasing the number of slices of data obtained and reducing the slice collimation (thickness) is an increase in the radiation dose to the patient. Initial scans delivered a dose of approximately 8 mSv compared with a conventional diagnostic coronary angiogram dose of 3–9 mSv. Recent MSCT papers show a substantial increase in dose to 13–21 mSv (table 1). This increase is understandable when the prerequisite of these cutting-edge papers is to produce the best results possible rather than to limit radiation exposure. There are techniques that help minimise radiation dose such as ECG gated *x* ray tube current modulation, which reduces the tube output by 80% during systole, when the acquired data adds little to coronary imaging. This has the advantage of reducing the dose by up to 50% but at the expense of inability to reconstruct end systolic images and greater sensitivity to arrhythmia.[13] The benefit of avoiding an invasive test is at least in part offset if the radiation dose incurred is increased by 300–700%. This remains the Achilles heel of MSCT coronary angiography and in the future some compromise will be needed between image quality and radiation dose.

CONCLUSION

Increasing the number of slices in MSCT clearly brings benefits in terms of diagnostic accuracy for detection of significant coronary disease. In particular it makes the imaging of smaller vessels more robust, allowing assessment of potentially the whole coronary circulation. Although improved with 64 slice scanners, heavy calcification remains a problem for MSCT, as does the high radiation burden.

How many slices are actually needed for CT coronary angiography depends largely on the population being studied. The high negative predictive value of MSCT, from four to 64 slice scanners, suggests that they are all generally acceptable for exclusion of significant coronary disease. However, 16 slice scanners offer significant advantages in terms of scan time and vessel size imaged and would be the minimum recommended choice for the robust exclusion of coronary disease. Conversely, if the desire is to assess coronary atheroma accurately in a patient with known ischaemic heart disease, using a scanner with the maximum number of detectors available is clearly beneficial.

The second consideration relates to the experience of the unit. Publications on MSCT coronary angiography have come from a limited number of centres with great expertise. Duplication of these results in departments with less experience will be difficult and, in this regard, there is no doubt that having a scanner with 64 or more slices will optimise the technique.

The population most likely to benefit from MSCT at present would seem to be those with a low pre-test probability of significant disease in whom the intention is to exclude rather than to quantify disease. Further studies targeting this patient group (with low disease prevalence) are needed to establish diagnostic accuracy. Although offering significant advances, 64 slice scanners still offer limited positive predictive values that probably do not justify their routine use for quantification of disease severity.

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STAMPS IN CARDIOLOGY

Artificial heart

The first permanent artificial heart was implanted on 2 December 1982 by William C De Vries at the University of Utah. The artificial heart was the Jarvik 7 and the patient, Barney Clark, who was suffering from a congestive cardiomyopathy, survived 112 days. The New York Times carried the front page article "Dentist close to death receives first permanent artificial heart". This illustrated cover from the New York Times Philatelic History of the United States commemorates the event. The cancellation mark is Salt Lake City, Utah and the date is 2 December 1992 – exactly a decade after the surgical milestone. The cover uses the 20 cent Health Research stamp, which was issued 17 May 1984 and the picture illustrated on the cover is that of Barney Clark.

The case was written up in the *New England Journal of Medicine*.[1]

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