The value of CT cardiac angiography and CT calcium score testing in a modern cardiology service in New Zealand: a report of a single centre eight-year experience from 5,237 outpatient procedures

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ABSTRACT

BACKGROUND: Computed tomographic (CT) cardiac angiography is of increasing value in several areas of patient management in cardiology. We assessed the ability of CT cardiac angiography to effectively 'rule out' severe coronary stenoses in patients presenting with 'atypical' symptoms and/or an equivocal stress test, which offers a new approach to the management of coronary artery disease. We also examined the use of the CT calcium score test in cardiovascular (CVS) risk assessment.

METHODS: From a large single centre (Mercy Hospital) in Auckland, using a prospectively acquired, comprehensive database, we audited the entire eight-year experience of 5,169 patients (7/8/06 to 31/1/14) who underwent 5,237 64-slice computed tomographic (CT) cardiac angiogram or CT calcium score tests (GE Lightspeed scanner).

RESULTS: From 5,169 patients there were 5,237 CT procedures. The mean patient age was 57 (SD 10) years; 42% patients were female. Of the 3,603 (69%) full CT cardiac angiogram scans, 3,509 (67%) included a calcium score test. One thousand four hundred and eighty-three (28%) of scans were a calcium score test only. Of the 3,603 (69%) full CT cardiac angiogram scans, it was possible to 'rule out' significant coronary atheroma (stenosis ≥50%) in 2,947 (82%) of these procedures. Of the 4,903 (94%) patients who had a CT calcium score test, in whom we could calculate the NZ Framingham-based CVS risk, it was possible to reassign 532 (22%) of these patients who were previously thought to be at 'low risk' to be at a higher CVS risk.

CONCLUSION: CT cardiac angiography has become established in the modern management of cardiology patients. It has particular value as a tool to 'rule out' severe coronary stenoses, and as a tool to give a more accurate assessment of CVS risk. It adds significant value to the care of many patients within an established cardiology practice.

Computed tomographic (CT) cardiac angiography has emerged as a reliable, non-invasive method to image the heart.[1] From the early 'four-slice' systems through to the '64-slice' machines, the technique has gathered a scientific and clinical momentum for use in several areas of cardiological management.[2] The currently available dual source, high definition and broad detector scanners (256- and 320-'slice'), are increasingly being used in clinical practice and will further advance the role of the technique.[3]

The principle benefit of CT cardiac angiography is to accurately image coronary arteries, using a venous injection of an iodine-based contrast agent. This is especially useful in patients at low or intermediate risk of ischaemia, who have atypical chest pain symptoms or equivocal results from functional assessments such as an exercise treadmill test or stress echocardiogram, and in whom it is suspected that the coronary arteries will be normal or 'near-normal'. The 'negative predictive value' of a standard 64-slice CT cardiac angiogram is between 97 to 99%,[4–5] and has become the management of choice for many of these patients who may have recurrent hospital admissions, or have a significant morbidity from their symptoms, and in whom a conventional (invasive) angiogram is felt to be too invasive.

Another extremely valuable role for CT cardiac angiography is for the assessment of cardiovascular (CVS) risk using the CT coronary calcium score test. This is performed using a non-contrast, ECG-gated scan of the heart,[6] with a very low radiation dose of approximately 1mSv, roughly equivalent to a bilateral mammogram,[7,8] CT coronary calcium scoring allows the detection and quantification of subclinical calcified coronary atherosclerosis, and has repeatedly been shown to be more accurate than conventional epidemiological-based risk factor assessment, including the entire Framingham-based equation.[9–11] Further, the impact of this knowledge improves patient compliance with lifestyle modification and preventative medication.[12]

There are also an increasing number of other applications for CT cardiac angiography.[13] These include the assessment of cardiac structures, especially the left atrium, before electrophysiology studies and in particular atrial fibrillation ablation. In addition, the assessment of the aortic valve and aortic root is widely performed prior to transcatheter aortic valve replacement (TAVR) procedures. Further, the accurate measurement of the aorta with aneurysmal dilatation, and the assessment of structures around the heart including the pericardium, cysts and masses are increasingly the role of CT cardiac angiography.

We aimed to assess our use of this technique over the life-span of our initial 64-slice CT machine to allow an understanding of its role and to refine our use of CT cardiac angiography in a busy practice.

Methods

Data collection

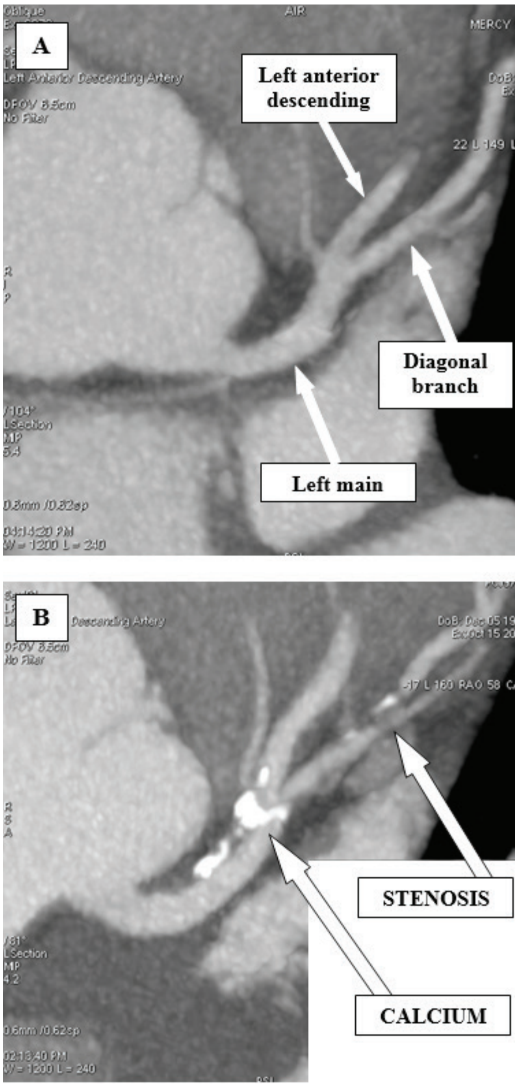
Data were prospectively collected from all patients presenting for a CT cardiac angiogram and/or a CT calcium score test. Consistent with National Guidelines for a new clinical service[14] care was taken to record relevant, but limited data, which was prospectively obtained by a practice nurse using a standardised data collection sheet from 7 August 2006 until 31 January 2014. The data collection form recorded patient demographics, relevant personal and family history, medication use and the results from the CT cardiac angiogram and the calcium score. Data were securely held at the practice.

Referrals for a full CT cardiac angiogram were from cardiologists and specialist physicians in Auckland and other North Island centres, for patients principally with equivocal exercise test changes and/or equivocal symptoms. Referrals for the screening CT calcium score test only, were from cardiologists, specialist physicians and also general practitioners, using an 'open access referral' for this non-contrast, low radiation dose risk-assessment tool.

All CT cardiac angiograms, including the calcium score, were performed by one of six radiographers using a standardised protocol for the 64-slice CT machine (GE Lightspeed). CT cardiac angiography gives clear images of coronary arteries without (Figure 1a) and with (Figure 1b) a severe stenosis.

The calcium score was derived according to the method of Agatston,[6] with these details incorporated into the CT machine.

Figure 1: Typical CT angiogram images (a) without stenosis or atheroma (b) with calcified atheroma and stenosis.



Quantification of the extent of calcium deposition is achieved with the reporting clinician following each artery or major branch of the coronary circulation and identifying calcium deposits within the coronary arteries. It is important that a clinician with an in-depth knowledge of the heart reports a calcium score test, to avoid non-coronary calcium, such as pericardial or mitral valve annulus calcification, being inadvertently added to the 'coronary score'. Agatston scores of zero indicate no calcification is present, whereas a calcium score of >100 units indicates 'significant' calcification; a calcium score of >400 units has been used as the threshold for 'severe' calcification.[11]

Patients gave informed consent to undergo the clinical investigation as a part of their clinical management. As an audit of current practice, individual patient consent was not required for this study, collection of relevant data being actively encouraged for a clinical service.[14]

Statistics

Continuous data are summarised as median and interquartile range or mean and standard deviation as appropriate. Differences in frequencies were tested using chi-squared procedures or Fisher's exact test as appropriate and differences between groups in continuous variables using the Wilcoxon independent groups test. SAS (SAS Institute Inc, v9.4, Cary NC, USA) was used to perform the analyses. All tests were two-tailed and a 5% significance level was used.

Results

We examined all 5,237 CT cardiac angiography procedures performed at Mercy Hospital, Auckland. The patient's mean age was 57 (SD 9.5) years, 42% were female, 80% were of European ethnicity (Table 1).

From 5,169 patients there were 5,237 CT procedures. The majority of scans, 3,509 (67%) were both a CT calcium score test for CVS risk assessment *and* a CT cardiac angiogram to image the coronary arteries, with 1,483 (28%) scans being a calcium score alone, and 94 (1.8%) a CT cardiac angiogram alone. A few procedures, 151 (2.9%) were for patients imaged for other reasons (Table 2).

Full CT cardiac angiogram

Of 3,603 full CT cardiac angiograms, 3,410 (95%) had clear images, with 193 (5%) having unclear images of some or all of the six main arteries or major branches of the coronary circulation (left main stem, left anterior descending, diagonal branches, left circumflex, intermediate/obtuse marginal branches, right coronary artery) (Table 3).

Of the 3,410 full CT cardiac angiograms with clear images in all six arteries or major branches, we calculated that 463 (14%) of scans had at least one artery coronary disease (as conventionally understood: ie one artery disease is LAD and/or diagonal, or circumflex and/or intermediate branches

Table 1: Baseline patient demographic data: all patient scans (n=5,237), full CT cardiac angiogram (n=3,603) and calcium score (n=4,992).

	Full CT angiogram (n=3,603)	**Ca score (n=4,992)**	**All patient scans (n=5,237)**
Mean age [years] (SD)	57 (9.4)	57 (9.3)	57 (9.5)
Sex (female)	1,592 (44%)	2,102 (42%)	2,194 (42%)
Ethnicity			
Caucasian	2,824 (80%)	4,046 (81%)	4,212 (80%)
Māori	91 (2.6%)	116 (2.3%)	129 (2.5%)
Pacifica	85 (2.4%)	93 (1.9%)	105 (2.0%)
Indian	223 (6.4%)	257 (5.2%)	270 (5.2%)
Asian	161 (4.6%)	183 (3.7%)	194 (3.7%)
Others	129 (3.7%)	154 (3.1%)	162 (3.1%)
Not reported	90 (2.5%)	143 (2.9%)	165 (3.2%)
Smoking			
Current	159 (4.4%)	194 (3.9%)	209 (4.0%)
Previous	1,237 (34%)	1,639 (33%)	1,718 (33%)
Never	2,191 (61%)	3,117 (62%)	3,258 (62%)
Not reported	16 (0.4%)	42 (0.8%)	52 (1.0%)
Hyperlipidaemia†	1,654 (46%)	2,091 (42%)	2,229 (43%)
Hypertension†	1,368 (38%)	1,640 (33%)	1,757 (34%)
Diabetes mellitus†	258 (7.1%)	277 (5.6%)	306 (5.9%)
FH of 1st degree relative with CVS Disease	1,568 (44%)	2,200 (44%)	2,269 (43%)

†Data missing from five patients.

Table 2: Initial and follow-up studies performed on 5,169 patients undergoing 5,237 CT scans.

	First scan	Second scan	Third scan	**TOTAL scans**
1. Full CTCA* AND Ca** score	3,482 (67%)	26 (41%)	1 (25%)	3,509 (67%)
2. Full CTCA NO Ca score	90 (1.7%)	3 (4.7%)	1 (25%)	94 (1.8%)
3. Calcium score only	1,461 (28%)	22 (34%)	0	1,483+ (28%)
4. Electrophysiological workup	79 (1.5%)	12 (19%)	2 (50%)	93 (1.8%)
5. Thoracic aorta imaging + TAVR***	52 (1.0%)	1 (1.6%)	0	53 (1.0%)
6. Other	5 (0.10%)	0	0	5 (0.10%)
Total	**5,169 (99%)**	**64 (1.2%)**	**4 (0.08%)**	**5,237 (100%)**

*CTCA: Computed tomographic cardiac angiogram.
**Ca: Calcium.
***TAVR: Transcatheter aortic valve replacement.
+ In three patients, calcium score not calculated.

Table 3: Clarity of images for full CT cardiac angiograms by the six arteries and major branches (n=3,603).

Images clear for ALL six arteries/branches	3,410 (94.6%)
Images unclear for SOME of the six arteries/branches	169 (4.7%)
Images unclear for ALL six arteries/branches	24 (0.7%)
Total	**3,603 (100%)**

Table 4: Significant stenoses and overall atheroma in the coronary arteries of full CT cardiac angiograms with clear images (n=3,410).

All arteries normal (no non-calcified atheroma and calcium score=0)	1,099 (32%)
Mild atheroma (<50% stenosis or calcium score ≥1) in at least one artery	1,848 (54%)
No significant stenosis (<50%)	**2,947 (86%)**
Left main	23 (0.7%)
1 artery disease**	303 (8.9%)
2 artery disease	98 (2.9%)
3 artery disease	39 (1.1%)
Significant stenosis (≥50%) in left main or at least one artery	**463 (14%)**

** 1 artery: LAD/Diagonals or Circumflex/Intermediate/Obtuse Marginals or RCA

or RCA) of ≥50% diameter stenosis (Table 4, Figure 2). Mild atheroma was seen in 1,848 (54%) of procedures and normal coronary arteries in 1,099 (32%) of procedures.

CT calcium score test

There were 4,992 scans with a CT calcium score, however, in three of these patients the calcium scan was performed as part of a 'calcium score only' investigation, but the score not calculated, as very marked calcification was present, and the clinical decision was made to not calculate the very high calcium score. In one third of scans: 1,812 (36%) patients had a calcium score of nil Agatston units, 1,407 (28%) of patients had a score of >100 units and 533 (11%) of patients a score of >400 units (Figure 3).

In 4,903 patients we compared the calcium score result with the current calculated Framingham CVS five-year risk score and risk levels (incorporating the advised New Zealand Guidelines group (NZGG) adjustments).[15,16] At least one data component of the Framingham risk score was missing

Figure 2: Overall atheroma in coronary arteries of patients having a full CT cardiac angiogram with clear images (n=3,410).

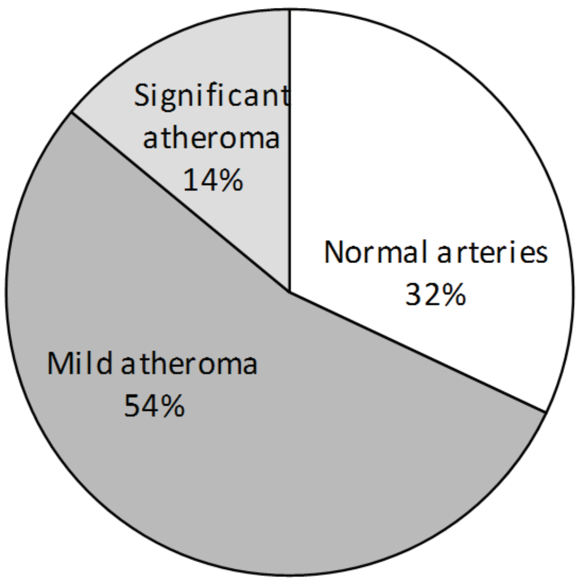
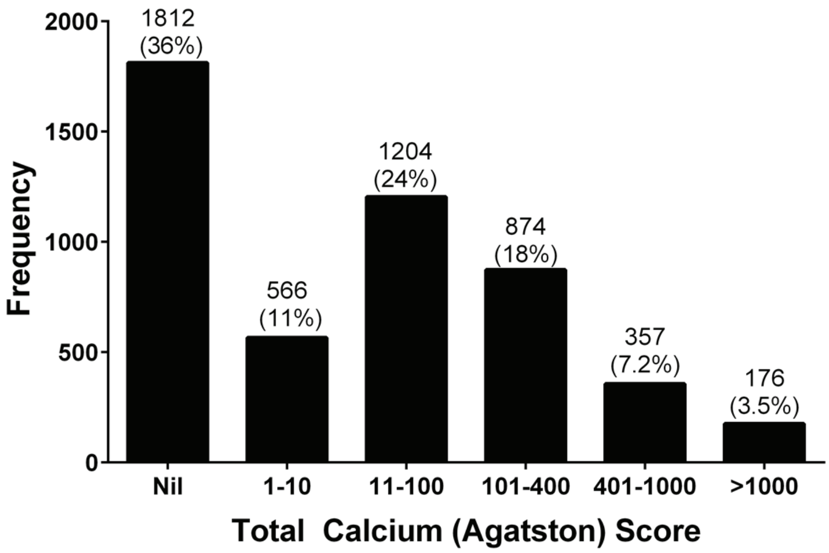


Figure 3: Frequency distribution of total calcium scores (n=4,989).*

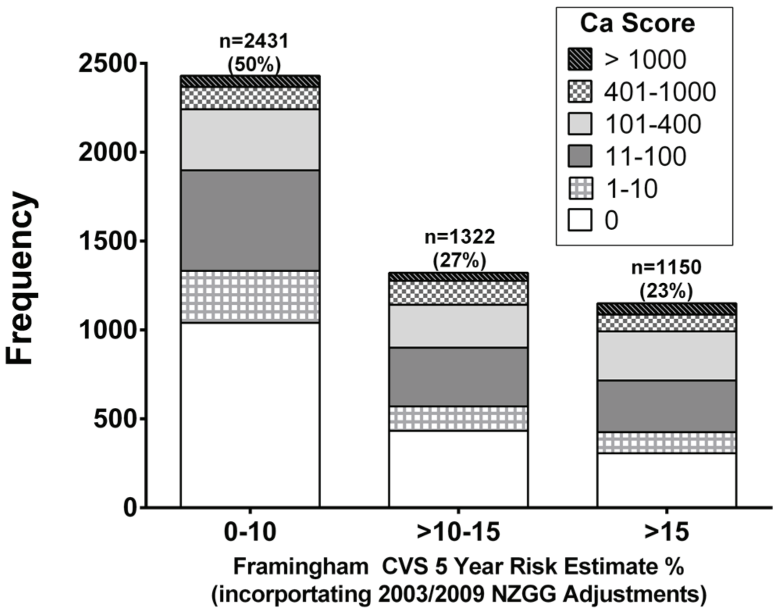


*Excludes three scans which did not have full calcium score calculated (patients with markedly calcified arteries, not further calculated).

from 86 patients, so they were excluded. Two patients were excluded because of missing calcium score and one patient was excluded with missing both the Framingham risk score data and the total calcium score. Half of the patients: 2,431 (50%) were calculated to be at *low CVS risk* as defined by the NZGG (0–10%, 5-year risk), of whom 1,040 (43%) patients had a calcium score of nil units, 532 (22%) a score of >100 units and 189 (7.8%) patients a score of >400 units (Figure 4, Table 5).

One quarter of the patients: 1,150 (23%) were calculated to be at *high CVS risk* as defined by the NZGG (>15%, 5-year risk), of whom 434 (38%) had significant calcium deposits with an Agatston calcium score >100 (Table 5). However, 307 (27%) patients of those calculated to be at high CVS risk (>15% 5-year risk) had no calcium within the

Figure 4: Frequency of patients with calcium scores with increasing Framingham CVS risk (n=4,903).



*Excludes two patients whose calcium score was not calculated, 86 patients missing at least one component of the Framingham risk score and one patient missing both total calcium score and at least one component of the Framingham risk score.

Table 5: Patients with calcium scores and calculated Framingham CVS risk (n=4,903).*

Five-year Framingham CVS risk				
Calcium score	**0–10%**	**10–15%**	**15+**	**P**
>400	189 (7.8%)	180 (14%)	157 (14%)	P<0.0001
>100	532 (22%)	421 (32%)	434 (38%)	P<0.0001
1–100	859 (35%)	468 (35%)	409 (36%)	P=0.99
Nil	1,040 (43%)	433 (33%)	307 (27%)	P<0.0001
Total	**2,431**	**1,322**	**1,150**	

*Excludes two patients whose calcium score was not calculated, 86 patients missing at least one component of the Framingham risk score and one patient missing both total calcium score and at least one component of the Framingham risk score.

coronary arteries, with an Agatston score of 0 (Table 5).

Radiation dose

The radiation dose was recorded in 2,666 (74%) of the 3,603 CT cardiac angiograms with a median dose length product (DLP) of 657 (Q1, Q3 551, 956), an effective median dose of 9.2 (Q1, Q3 7.7, 13.4) mSv. The radiation dose was recorded in 4,054 (81%) of the 4,992 CT calcium score tests, with a medium DLP of 81 (Q1, Q3 57, 103), an effective dose of 1.13 (Q1, Q3 0.79, 1.44) mSv.

Discussion

The assessment of patients with chest pain and suspected coronary artery disease is a common clinical situation for clinicians.

A careful history and examination by an experienced doctor is the key component to making an accurate diagnosis. Subsequent investigations traditionally use functional methods of assessment: using treadmill electrocardiographic testing, stress echocardiography or stress scintigraphy, with the aim to demonstrate or exclude areas of ischaemia, which are suggestive of a flow limiting stenosis within a coronary artery. However, these functional tests can only *suggest* a likelihood of severe coronary disease and not *confirm* the diagnosis of coronary artery atheroma. Confirmation of the diagnosis requires the imaging of coronary arteries, which has previously been limited to the invasive technique of coronary angiography.

Over the last 10 years, CT cardiac angiography has significantly changed the landscape for the assessment of chest pain and suspected coronary artery disease. With the ability to accurately image coronary arteries with a non-invasive technique, there is now an "intermediate step" for assessment, which bridges the gap between the clinical review with functional tests, and the invasive cardiac angiogram.

Although temporal and spatial resolution of CT cardiac angiography remain inferior to conventional invasive coronary angiography, nonetheless high diagnostic accuracies have been demonstrated for the detection of significant coronary artery disease. The most appropriate use of a CT cardiac angiogram is in patients in whom the clinician is looking to "rule out" significant coronary stenoses in a low- or intermediate-risk patient.[13] If a clinician believes a flow limiting stenosis is present, or probably is present, in a high cardiovascular risk patient, then a conventional, invasive coronary angiogram is usually indicated.

The advent of the 64-slice CT cardiac angiogram has allowed for consistent and reliable coronary imaging. We have shown that from a careful programme of 3,612 patients receiving a full CT cardiac angiogram, in 95% of patients, clear images were seen of all six main arteries or major branches. With this, the ability to "rule out" significant coronary wall stenoses was successful in 86% of patients, while 14% of patients were reported to have possible severe stenoses. These may not have otherwise been detected, following the patient's presentation with either atypical chest symptoms or an equivocal functional test. Patients were then managed with a subsequent invasive angiogram, and revascularisation as required, or were managed medically, but with the knowledge that significant coronary wall atheroma was present with appropriate subsequent preventative strategies. The potential benefit of this non-invasive coronary assessment is major, and CT cardiac angiography has developed into an important adjunct to a cardiological programme.

With the development of CT cardiac angiography supplementing conventional invasive angiography for making a more accurate diagnosis of anatomical coronary disease, the value of functional testing may become more one of predicting prognosis. There is a wealth of data which has demonstrated the ability of functional stress testing to separate low risk from higher risk patients, with electrocardiography, echocardiography, nuclear scintigraphy and magnetic resonance imaging.[17–20]

Acquisition

Coronary CT angiography involves a venous injection of an iodine-based contrast agent, with the CT scan being "gated" to the ECG; images being obtained during diastole, when the coronary arteries are relatively still.[2]

The key for patients undergoing a cardiac angiogram is for the heart rate to be lowered to <60 beats per minute. Even with the most advanced CT cardiac angiography machines, if the coronary artery is moving at the time that the imaging is undertaken, clear images are not seen.[21] The use of oral as well as intravenous beta-adrenergic blocking medication (usually metoprolol tartrate) is necessary to lower the heart rate. Hence patients with a significant contraindication to 'beta-blockers' are unsuitable for this technique.

Overweight patients give less clear images, as do older patients, who are more likely to have extensive calcification, which obscures full luminal assessment. Patients in atrial fibrillation or with frequent ectopic beats are also less able to give clear images of the coronary arteries, and hence are also often unsuitable for this technique.

Haemodynamically stable patients are suitable whereas those who are unstable and in whom it is dangerous to slow the heart rate to < 60 beats per minute should have their coronaries imaged with a conventional invasive cardiac angiogram.[22]

Radiation dose

The radiation dose for the acquisition of CT cardiac angiography with a 64-slice machine is similar to that of an invasive cardiac angiogram at between 5–10mSv.[7,8,23] However, the current range of 128 or 256 slice detector CT cardiac angiogram machines can now obtain good images with a radiation dose generally between 1–4mSv, which is less than is delivered with a conventional cardiac angiogram.[3] This radiation dose can be compared with the annual background radiation dose in New Zealand of 3mSv. The radiation dose for a CT calcium score test is even lower, at about 1mSv, approximately the same dose as a bilateral mammogram.[7,8]

Analysis

Complex computer software allows the x-ray images to be recreated in axial, double oblique, maximum intensity projection, curved multiplanar formats and three-dimensional volume rendered reconstructions. Reporting clinicians require extensive training and experience with the technique to optimally integrate a new CT cardiac angiogram programme into a cardiological service.[22]

Acute chest pain

Randomised controlled trials have established the useful role of coronary CT coronary angiography in patients presenting to emergency departments with undifferentiated acute chest pain and negative serum troponin and normal ECG recordings.[24] However, our outpatient programme did not include the assessment of patients with acute chest pain.

Coronary artery calcium scoring

The conventional *epidemiological* methods of the assessment of CVS risk is currently being challenged by the advent of *imaging* methods.[25] The intuitively attractive method of visualising the actual calcified coronary atheromatous burden in an individual patient has also been shown to be a more accurate method of risk assessment.[9,10]

A calcium score of >100 Agatston units conferred a 10-fold increase in risk, in the St Francis heart study of 4,613 asymptomatic people followed for 4.3 years compared with a calcium score of zero.[9] Further, the

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coronary calcium score alone was superior to the Framingham risk score at predicting CVS events (area under the receiver-operating characteristic (ROC) curve of 0.79 +/- 0.003, p=0.0006), and enhanced the risk stratification of those falling into the Framingham categories of low, intermediate and high risk (p<0.0001).[9]

A calcium score of >400 Agatston units conferred a risk of up to 30 times the risk of a population with a calcium score of zero units in the Multi-ethnic study of atherosclerosis (MESA), in 6,814 asymptomatic participants at a median follow-up of 3.75 years.[26] It was recommended that cut points be used on the absolute calcium score level of 100 and 400 Agatston units.[26]

In addition, patients without calcification, with a calcium score of nil Agatston units, have an excellent 15-year survival.[27] Of 9,715 individuals (mean age 53.4 +/- 10.5 years, 59% male) undergoing calcium score screening, at a mean follow up of 15 years, 95% of individuals with a calcium score of zero were alive compared to 85% of individuals with a calcium score of >zero.[27] Interest has been given to patients who are calculated by epidemiological methods to be at high CVS risk, but are found to have a low calcium score, with the potential to reassign these patients to a lower risk group.[28]

The ability to more accurately assess CVS risk with imaging methods, compared to the traditional epidemiological methods, has led to groups looking to 'refine' CVS risk inaccuracies. The current American CVS risk guidelines have combined four very large epidemiological studies into one equation to assess risk, and have recommended that for patients with a CVS risk of 7.5% and above over 10 years should be recommended for statin treatment.[29] Using this guideline, approximately 33 million Americans would be eligible for statin management using the epidemiological equation on its own. To try to refine this number of patients eligible for statin use, a major paper from the USA Government-funded MESA study has reviewed patients who would fit these guidelines, and have looked at the calcium score of those recommended to consider statin therapy. Forty-one percent of these patients were shown to actually have a calcium score of zero, and would therefore really be at very low risk.[30] Hence the combination of an epidemiological CVS risk tool with a more accurate calcium score test may be a model to better refine CVS risk assessment in populations. The relative cost implications of these strategies are yet to be carefully explored, but are needed.

Study limitations

We have described the clinical use of CT cardiac angiography, including the actual reports of the scans. We do not have a correlation with invasive cardiac angiography in the 14% of patients with atheroma reported to be >50% luminal stenosis. Neither do we have follow-up data on patient management. However, this study is of the actual use of CT cardiac angiography to demonstrate the strength of the procedure, namely to exclude severe stenoses from a group of patients with atypical symptoms or equivocal results from stress testing.

The study cohort for coronary artery calcium scoring is a selected population, which may not be representative of the New Zealand population, and may under-represent or over-represent the degree of coronary calcification across New Zealand.

Conclusions

CT cardiac angiography has become established in the modern management of cardiology patients. It can be readily integrated into established practice, and adds significant value to the care of many patients.

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Competing interests:

All authors excepting Grag Gamble received payment for reporting of Cardiac CT scans from the 'Auckland Heart Group' private cardiology practice or from working at the Mercy Radiology Cardiac CT scanner. As a part of their private cardiology practice Chris Ellis, Colin Edwards, Niels van Pelt, Ruvin Gabriel, Boris Lowe, John Ormiston and Malcolm Legget have a share-holding in the 'Auckland Heart Group', which itself has a minority share in the ownership of the Mercy Radiology Cardiac CT scanner. Greg Gamble received payment from the Auckland Heart Group for data management and statistical analysis of this work.

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