Cardiac imaging technologies

A discussion paper

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Contents

Executive summary

- This paper is a brief commentary on the nature and use of cardiac imaging technologies and is intended to provide a basis for further discussion.
- There has been a significant increase in the number of investigations performed on patients with suspected heart disease. Over the period 1989–90 to 1991–92 there has been an increase of 118 per cent in the use of coronary angiography, nuclear medicine and ultrasound testing. In this period, Medicare Benefits paid for these three categories of tests rose from $17.0m to $34.4m.
- The increasing use of echocardiography, a non-invasive test, may be related to the repeated use of the test on the same patient for the purpose of physician reassurance.
- There is little direct evidence that benefits, in terms of effect on patient outcome, are commensurate with the apparent increase in the use of cardiac imaging tests.
- A proposed framework for the development of diagnostic algorithms is outlined, suggesting that a diagnostic matrix might be constructed to provide guidelines for the use of cardiac diagnostic tests.
- A survey of cardiac imaging practice in both the public and private sectors to establish the numbers of diagnostic units and the existing patterns of practice would be desirable.
- A number of newer cardiac imaging methods are becoming available. Their future role in relation to existing tests needs to be defined.

Introduction

This review of cardiac imaging techniques has been prepared to provide a brief commentary on the nature and use of the variety of competing diagnostic methods which are available for the investigation of the symptoms of heart disease. This paper is intended as a vehicle for further discussion.

Apart from the investigation of symptoms, imaging techniques are used in the management of conditions, such as stenosis and myocardial infarct, and in the follow-up of patients with ischemic heart disease. Asymptomatic patients may be screened through stress testing as part of a physical examination.

Coronary heart disease (CHD) is a leading health problem of the Western world. Some 33,000 Australians die of CHD each year(1). A much higher number have existing coronary disease, and are at different degrees of risk. For these persons the disease may be asymptomatic, may give rise to chest pain, heart beat irregularity and angina or may lead to mild ischemic attacks. The status of the disease may be congenital, lifestyle-related or age-related, (or a combination of these). The annual costs of cardiovascular disease (including both CHD and stroke) in Australia have been estimated to be approximately $1,858m in 1989–90 values, of which $893m was in direct costs of health care(2).

Given the high mortality and morbidity associated with heart disease, it has become regular practice to investigate patients for the presence of CHD with view to lifestyle modification, or medical or surgical intervention. Testing may include one or a combination of the following procedures:

- a chest x-ray (to detect enlarged heart)
- an electrocardiogram while the patient is at rest
- a maximal performance stress electrocardiogram
- an echocardiogram (ultrasound evaluation of the chambers, walls and valves of the heart)
- Holter monitoring (24 hour ECG)
- radioisotope studies, such as investigations with thallium, to diagnose obstructive coronary-artery disease
- a selective coronary arteriogram or coronary angiogram, involving the insertion of a catheter into the coronary arteries via the femoral artery, and the injection of a radio-opaque dye to determine the function of the arteries or to detect the presence of viable myocardium.

The function of the heart may also be examined by dynamic CT, MRI or PET studies to determine the presence of stenoses or narrowings of the arteries and to assess their function. However, these technologies are not generally used in the assessment of cardiac status in Australia. A brief description of developments in imaging technologies is given in Appendix A.

All tests involve some element of risk to the patient and have the potential to produce either false negative results (disease actually present but not detected, patient may not be offered appropriate treatment) or false positive results (disease actually absent, but incorrectly diagnosed, inappropriate treatment may be offered). In addition to the consequences of incorrect results, side effects of tests may have medical and psychological implications for the well-being of the patient.

Diagnostic problems

Most cardiac tests in adults are used to determine the health and functional status of the coronary arteries. They are also used to detect congenital defects or to examine the operation of valves and the efficiency of the heart in pumping blood (ejection fraction). Typically, the areas where infarction occurs are the right coronary artery and the left main coronary artery which divides into the left circumflex branch and the left anterior descending branch. If either of these arteries become blocked, the tissues served by those arteries may die (myocardial infarction).

A patient may present for cardiac imaging following either mild or severe symptoms. There are currently few standards for the ordering of cardiac investigations. Numbers of major cardiac surgical procedures performed in Australia between 1986 and 1990 are shown in Table 1. In addition, some 30,000–40,000 other heart surgery procedures such as valve replacements take place each year. A summary of cardiac diagnostic investigations, for which Medicare Benefits were paid, in shown on Table 2.

Table 1: *Cardiac procedures in Australia—1986 to 1990*

Procedure	1986	1987	1988	1989	1990
Coronary angioplasty	1,840	2,383	3,153	4,219	4,904
By-pass surgery	8,048	9,236	9,566	10,531	11,381
Heart transplant[(a)]	35	29	48	90	98

(a) Includes heart/lung transplants.

Source: Australian Institute of Health and Welfare[(3)]
National Heart Foundation of Australia[(4, 5)]

Table 2: *Cardiac investigations for which Medicare benefits were paid, 1990–91*

Investigation	Number
Coronary angiography	21,000
Nuclear medicine	22,000
Echocardiography	91,000
ECG (continuous)	42,000
Exercise ECG	123,000
12 lead ECG	1,100,000

Note: Public hospital in-patient data not included.

Source: Health Insurance Commission

The total number of investigations would be higher than shown in Table 2 which does not include investigations performed in public hospitals on public patients. A relatively small proportion of investigations are related to the surgical management of patients with heart disease. The great majority are performed as routine examinations for suspected heart disease.

Services to public hospital inpatients and outpatients which are not included in the Health Insurance Commission data base account for about 17 per cent of all services.

In addition, services to veterans, workers compensation patients, motor car third party insurance cases and industrial medical services may account for another six to seven per cent[6]. In general, about one-quarter of all medical services are not included in HIC data. However, the proportion of diagnostic services excluded may well be higher. A recent survey of nuclear medicine services by the Australian Radiation Laboratory showed that only about 60 per cent of such services were recorded by the HIC[7].

Thus the data shown in Tables 2 to 6 may underestimate the total cardiac diagnostic services by 25–40 per cent. This would be consistent with the level of activity in the cardiac area in the major public hospitals in Australia.

Use of cardiac imaging technologies

An overview of cardiac imaging modalities should take account of a number of competing techniques which have varying cost, convenience and diagnostic accuracy. An examination of expenditure data on Australian use of cardiac imaging (Table 3) shows that there is a relationship between cost and utilisation. Although this would be expected, there would be great value in information showing the relationship between frequency of use and accuracy of diagnosis. Unfortunately such data are not available. There appears to be considerable variation between hospitals and practitioners in the use of various cardiac imaging modalities. While some variation in utilisation due to economic rather than clinical factors might be expected, it would appear that individual and departmental preferences for particular technologies is an important factor. For example, there seems to be considerable variation between different hospitals with regard to the relative importance of ultrasound and nuclear medicine tests.

Table 3: *Use of cardiac tests in Australia, 1990–91*

Item	MBS Item no.	Number	Total cost ($)	Avg. cost ($)
X-ray—thorax		1.43m	60.0m	42
12 lead ECG	(908/909)	1.1m	20.4m	19
Continuous ECG (Holter)	(915)	42,107	4.3m	103
Exercise ECG	(916)	122,862	11.0m	90
Echocardiography (M-Mode)	(9066)	78,718	10.4m	132
Echocardiography	(913)	12,647	0.8m	66
Coronary arteriography	(7013)	20,899	7.9m	378
Nuclear medicine				
Thallium —single study	(8727)	569	0.2m	343
Thallium —combined study	(8732)	13,713	7.6m	554
Gated cardiac study	(8740)	7,417	1.6m	216
Gated cardiac study	(8741)	1123	0.3m	271

Note: Public hospital in-patient data not included.

Source: Health Insurance Commission

Tests range in cost and complexity from a plain cardiac x-ray through to a PET study, suggesting a need for a diagnostic/cost algorithm to indicate how different diagnostic problems can be addressed most appropriately while balancing need for high accuracy with the cost of the test and its place in patient management. Although accurate costs per examination are not available for the more expensive cardiac studies, Medicare Benefits data give an indication of expenditure on commonly performed investigations. Table 4 gives data on expenditure on three categories of imaging procedure and Table 5 indicates the variation between States in the use of these tests as recorded by the HIC, based on services for which Medicare Benefits were paid.

Table 4: *Medicare benefits paid for selected cardiac investigations 1989–90 to 1991–92*

Type of test (MBS item no.)	MBS benefits paid $m		
	1989–90	1990–91	1991–92
Nuclear medicine			
—thallium (8732)	4.8	7.6	10.0
—gated (8740)	1.3	1.6	1.7
Coronary angiography (7013)	7.0	7.9	9.0
Echocardiography (9066)	4.1	10.4	13.7
Total	17.2	27.5	34.4

Source: Health Insurance Commission

Table 6 shows the increase in the three major cardiac investigation modalities on which Medicare Benefits were paid over the years 1989–90 to 1991–92. The increase in the use of echocardiography over that period partly reflects developments in technology with the use of Doppler colour ultrasound to show the direction of blood flow. However, it should be noted that changes in utilisation may also be due in part to the transfer of services from public hospitals to private clinics.

Table 5: *Numbers of selected cardiac investigations by State, 1990–91*

Type of test[(a)] (MBS item no.)	NSW	Vic	Qld	WA	SA	Tas	ACT	(b)	Total
Nuclear medicine									
—thallium (8732)	9,668	1,712	1,006	549	289	83	382	24	13,713
—gated (8740)	5,298	1,298	206	96	111	44	267	43	7,417
Coronary angiography (7013)	7,868	5,823	2,017	2,697	1,911	332	236	15	20,899
Echocardiography (9066)	39,283	17,134	9,895	6,890	4,903	789	762	62	78,718

(a) Description of cardiac investigations:
- —8732 Myocardial perfusion study using thallium (stress and reperfusion)
- —8740 Gated cardiac blood pool study
- —7013 Selective coronary arteriography
- —9066 Echocardiographic examination of the heart, M-Mode and 2-Dimension real-time

(b) Unknown

Source: Health Insurance Commission

Table 6: *Increase in Medicare benefits services for selected cardiac investigations 1989–90 to 1991–92*

Type of test (MBS item no.)	Number of services 1989–90	1991–92	Per cent increase
Nuclear Medicine			
—thallium (8732)			
—gated (8740)	18,264	24,868	36
Coronary angiography (7013)	19,234	23,591	22
Echocardiography (9066)	31,910	102,878	222
Total	69,408	151,337	118

Source: Health Insurance Commission

Growth in cardiac imaging

A matter of interest is the rate of growth in cardiac diagnostic services. Table 6 shows an increase of 118 per cent in the three major diagnostic modalities over the past two years, as recorded in the HIC data base. Proponents of these technologies, coronary angiography, nuclear medicine and echocardiography, make similar claims about their capabilities in diagnosis of coronary artery disease, prognostic stratification of patients and evaluation of patients after revascularisation procedures. Such competing claims may result in an increased use of all tests as different combinations of diagnostic tests are used.

While it is difficult to comment on trends in services for which Medicare benefits are paid, given that there are services provided in public hospitals and that there may be transfers of services from public to private diagnostic clinics, it is interesting that the greatest increase is in the least invasive test, echocardiography. The greater increase in the use of echocardiography may be due to the fact that a non-invasive test can be repeated on a patient. The number of echocardiography services may have an uncertain relation to the number of patients, whereas it would be unlikely that the same patient would receive more than two or three invasive tests in the one year.

On balance it may be that echocardiography is providing useful information non-invasively and, on the basis of current reimbursement, is the least expensive of the three cardiac imaging tests. However, because of the increase in the number of services, the cost of echocardiography increased from $10.4m in 1990–91 to $13.7m in 1991–92 (+ $3.3m) whereas the cost of coronary angiograms only increased from $7.9m to $9.0m (+$1.1m).

A large increase in the numbers of a relatively inexpensive test such as echocardiography can have a greater effect on the overall health budget than a small increase in relatively expensive tests (MBS fee $525) such as coronary angiography. It is of interest to consider the effect of patient management or outcome of the relatively large increase in echocardiography tests. If a major outcome is reassurance to the physician because patients are being regularly monitored, then perhaps this assurance could be obtained by other means such as clinical examination at less overall cost to the health system. At present, outcome data are not readily available to assess the impact of these additional tests.

An interesting question is how well different cardiac tests perform in routine clinical use in relation to particular diagnostic problems. Research on imaging techniques is usually performed on selected populations in a controlled setting and the results are not necessarily applicable to the general population. As well, the accuracy of a test depends on the experience of the user in its interpretation and on the prevalence of the condition in the population. A confounding factor is that tests are usually used in combination, so that diagnostic accuracy is related to the sum of the information of all the tests (and of the clinical history of the patient), rather than to a single test.

There is a great deal of research interest in newer technologies for the diagnosis and management of cardiac disease. Such research is partly associated with the increase in diagnostic and surgical cardiac procedures in the USA where approximately four million tests or procedures are performed each year.

Areas of interest for diagnosis of cardiac disease are developments in MRI, PET and Cine CT. Use of these technologies has as yet had little impact in Australia for cardiac testing, with only two PET centres and eight public MRI units in operation, and no cine CT units. (A brief overview of developments in each technology is given in Appendix A). It is unlikely that these three modalities will have a significant effect on the practice of diagnostic cardiology in Australia in the near future.

Development of diagnostic algorithms

If each type of test had a defined diagnostic performance for a given clinical problem, there would be an opportunity for studies comparing the effectiveness of the different methods. However, it appears that there is little consensus on diagnostic accuracy in the routine situation and imaging modalities are frequently used on the basis of availability and physician preference.

An analysis of the usefulness of cardiac imaging examinations would involve classifying the cardiac tests in relation to the type of diagnostic problem to be investigated. A list of symptoms for adults and children might be constructed as follows:

	Adults
Preliminary	vague chest pain, search for underlying coronary artery disease
Acute	patient presents with acute myocardial infarction
Therapeutic	surgical decision required for angioplasty or by-pass graft
Post-operative	monitoring of re-perfusion following treatment
	Pediatric
Pediatric/congenital	detection of suspected abnormality
Acute	pediatric surgery
Monitoring	review of cardiac function

The sequence of tests to be performed could then be decided, having regard to both cost and risk to the patient. As indicated in Table 3, based on Medicare Benefits Schedule fees, cardiac x-ray and exercise ECG are the least expensive imaging procedures, while echocardiography is the least invasive and is comparable in cost. Costs rise to over $500 per investigation for thallium testing and for coronary arteriography, with an increase in risk to the patient.

If different imaging modalities are assumed to be useful for differing clinical conditions, an efficiency matrix might be constructed of modality by age/sex and suspected pathology linked to cost of the investigation and the risk to the patient.

The relationship between the abilities of each imaging modality to diagnose particular conditions could first be considered:

Cardiac pathology	Imaging modality
Pediatric abnormalities	• Ultrasound/MRI
Elderly patients —valve disease	• Ultrasound
Coronary artery disease	• Exercise ECG Exercise echocardiography Nuclear medicine Coronary arteriogram PET
Pre-surgical evaluation for revascularisation, transplant	• CA MRI/PET
Surgery, CABG/PTCA	• CA/DSA
Post-surgical evaluation	• CA/PET

A suitable sequence of investigations then needs to be established, based on cost, availability and risk to the patient.

In the case of suspected coronary disease a non-invasive test such as exercise EGG might be selected as being is readily available, non-invasive and low in cost. If the results were equivocal, the clinician might then make use of a thallium stress test, with associated injection of radiosotopes, waiting time for the patient while test is completed and increased cost. However, if the clinician had access to echocardiography, then a stress echocardiography test might be preferred, given its ability to view regional wall motion abnormalities and to identify stress-induced ischemia. Other relevant factors might be the relatively low cost and the non-invasive nature of that test.

On the other hand, if the clinician suspected the presence of severe coronary disease, a decision might be made to proceed directly to an invasive and costly test such as a coronary angiogram. This decision could be based on the need for information to allow appropriate decisions to be made regarding PTCA or CABG. Thus the selection of an invasive test, posing some risk to the patient, may be justified in terms of the expected benefit to the patient from information obtained from the test. Jelinek[8] has suggested that in these cases, the normal sequence of tests, exercise ECG plus coronary angiogram, might be reversed, with the ECG only used as an aid to interpret difficult coronary angiograms, if required.

It can be seen that there are several competing technologies for investigation of a number of cardiac problems, so there will be an exercise of choice by the clinician as to which test or sequence of tests is ordered. Whereas ultrasound is capable of showing blood flow images, nuclear medicine studies have the advantage of showing metabolic uptake. It appears that coronary angiography will remain the gold standard for diagnosis, particularly where surgery is contemplated, but that other imaging tests will be used extensively. However, the incremental effect of additional diagnostic information on patient management or outcome, compared with a review of symptoms and clinical examination, remains poorly defined.

There are various ways in which a diagnostic matrix might be constructed, depending on the age of the patient, the type of clinical problem to be investigated and the cost and availability of the tests. The development of such a matrix would provide guidelines for the use of cardiac diagnostic tests and could potentially avoid unnecessary risks to patients and reduce costs to the health care system.

A matrix for imaging services would need to have regard to the following factors:

— presenting symptoms;
— results of clinical assessment;
— clinical problem to be solved;
— performance of test (sensitivity & specificity)
— cost of test;
— risk to patient;
— availability of test;
— age of patient;
— severity of disease;
— availability of patient management options.

An inexpensive, non-invasive, readily available test may be preferred to an invasive test such as a coronary angiogram.

Conclusions

Cardiac imaging is likely to continue to be a growing area of increasing complexity due to the ageing of the population, pressures to investigate CHD, and to new developments in technology. For example, repeat coronary angiograms are now accepted practice due to better procedures and contrast agents leading to reduced morbidity. The development of management techniques like PTCA are likely to lead to more interventions as the technique may be repeated on the same patient. The National Heart Foundation noted that the number of PTCA procedures increased by 16 per cent in 1990 over 1989, an indication of the continuing growth of angioplasty among the range of cardiological interventions.

The bulk of the expenditure on cardiac imaging is involved in ECG tests and exercise stress tests. It may be useful to consider if all such tests are necessary having regard to the anxiety to the patient caused by false positive findings, overall costs and impact on future management.

The main conclusion of this brief review of cardiac imaging issues is that the rate of testing is rising rapidly. There is little direct evidence that benefits, in terms of effect on patient outcome, are commensurate with the apparent increase in the use of cardiac imaging tests. It would seem appropriate for there to be investigation of the reasons for these increases and studies of the cost-effectiveness of imaging methods in the context of overall patient management. As a first step a survey of cardiac imaging practice seems warranted to establish numbers of diagnostic units and existing patterns of practice in Australia in both the public and private sectors. As well, newer and more expansive tests are becoming available and their role in relation to existing tests need to be defined. There is a need to collect further information to enable the development of comprehensive matrix of the role of diagnostic tests in the management of cardiac disease.

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Abbreviations

ACNP	American College of Nuclear Physicians
A/D	Analogue to digital converter
AMI	Acute myocardial infarction
ANSTO	Australian Nuclear Science and Technology Organisation
ANZAPNM	Australian and New Zealand Association of Physicians in Nuclear Medicine
ASUM	Australasian Society of Ultrasound in Medicine
CA	Coronary angiography/arteriography
CABG	Coronary artery by-pass craft
CAD	Coronary artery disease
CCD	Charge coupled device
CT	Computed tomography
DA	Digital angiography
DSA	Digital subtraction angiography
ECG (EKG)	Electrocardiograph
FDG	Fluorine-18-fluorodeoxyglucose
FOV	Field of view
Gd-DTPA	Gadolinium Diethylenetriaminepentaacetic acid
HIC	Health Insurance Commission
IA	Intra arterial
IHD	Ischemic heart disease
II	Image intensifier
IV	Intra vascular
Kev	One thousand electron volts
LAD	Left anterior descending artery
LMCA	Left main coronary artery
MBS	Medicare benefits schedule
MRI	Magnetic resonance Imaging
NHF	National Heart Foundation
NM	Nuclear medicine
NSQAC	National Specialist Qualifications Advisory Committee
PET	Positron emission tomography
PTCA	Percutaneous transluminal coronary angioplasty
Q wave	ECG Q wave
RACR	Royal Australasian College of Radiologists
SCA	Selective coronary arteriography
SNM	Society of Nuclear Medicine

SPECT	Single photon emission computed tomography
ST wave	ECG ST wave
Tl-201	Thallium-201
TE	Transesophageal echocardiography
Tc-99m	Technetium 99m
TPA	Tissue plasminogen activator
US	Ultrasound

Appendix A

Cardiac imaging technologies

The notes in this appendix are provided to give further information on some aspects of cardiac testing. They do not seek to provide a comprehensive outview of the technologies concerned

Exercise, ECG and nuclear medicine

It is not clear how the accuracy of ECG exercise testing compares with tests such as thallium-201 exercise testing. Doubts about the accuracy of exercise ECG in detecting coronary disease have revolved around the proportion of false negative readings. Such problems may be minimised with careful patient selection by a standard protocol and by the use of a maximum ECG stress test to detect disease if present. The argument revolves around the point that irregularities are not detected at a sub-maximal test and thus the necessity for testing the patient to exhaustion. Stress testing has led to concern about the number of coronary events that occur while a patient is undergoing maximal stress testing.

A number of large scale prospective studies have demonstrated the relative safety of maximal exercise testing. Cahalin et al.[9] documented the experiences of 10,577 subjects, 41 per cent of whom had documented coronary artery disease. The data revealed a morbidity rate of 3.8 per 10,000 exercise tests and a mortality rate of 0.9 per 10,000 tests. The authors concluded that maximal exercise testing can be performed safely when:

- contraindications to testing are followed;
- end-points for testing are well defined;
- the patient's signs and symptoms are thoroughly assessed before, during and after the exercise test; and
- properly trained professionals perform the exercise test.

A prospective study by Gibbons et al.[10] on 71,914 subjects from 1971 to 1987 with a low prevalence of known heart disease documented in six major cardiac complications including one death. No complications occurred in the last ten years. The overall complication rate in men and women was 0.8 per 10,000. The authors concluded that maximal exercise testing appeared safer than previously reported and appear to be getting safer with time. Major complications were defined as myocardial infarction, ventricular fibrillation, ventricular tachycardia requiring treatment, atrial arrythmias requiring treatment, a systole, stroke and death. Symptoms not included as complications in the study were unsustained supraventricular arrythmias, transient ventricular tachycardia not requiring intervention, chest pain, systolic blood pressure drop that rose with cessation of exercise and severe vasovagal bracycardia not requiring intervention.

Since late 1978 the test protocol has been modified to include a mandatory post exercise cool-down involving a 3–5 minute walk before lying down. In 45,000 tests since then there have been no complications. The authors concluded that the most serious complications are likely to occur during recovery and not during the exercise portion of the test. Thus ECG monitoring for 10 minutes after cessation is recommended to allow the heart to return to normal.

As regards sub-maximal exercise testing (stopping an exercise test at 85 per cent of predicted maximum heart rate), Froelicher[11] has noted that stopping a test at an arbitrary level taxes the most vulnerable patients to a relatively greater extent while the results on the less impaired are inconclusive. In a study on the time of occurrence of abnormality during maximum exercise, Gibbons et al.[12] noted that if the tests had been stopped at 85 per cent of predicted maximum heart rate, 39 per cent of the first abnormalities would have been missed. In those with no history of heart disease, these abnormalities were as predictive of subsequent coronary events as those that occurred at lower heart rates.

The results from large scale prospective studies would appear to suggest that maximal exercise ECG tests are relatively safe if contraindications to testing are followed, indications for stopping are observed and well-trained persons administer the test[13]. What remains to be determined is the accuracy of the exercise ECG test in relation to nuclear medicine tests, given the apparent advantages of exercise as regards cost and the non-invasive nature of the test when compared with the injection of thallium-201. Therefore it would appear that in screening for suspected coronary artery disease thallium-201 testing should not normally be used in addition to exercise ECG testing. However, there are cases where abnormalities are likely to impair the interpretation of the ECG[14,15].

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Nuclear medicine and SPECT

The principal use of thallium-201 perfusion scanning is as an adjunct to exercise testing. During 1990–91 some 14,000 investigations, excluding public hospital in-patients, were conducted in Australia at a cost of $7.8m. The isotope thallium-201 is injected intravenously at peak after a standardised exercise stress test has been undertaken. The heart is imaged with a gamma camera. The isotope is distributed homogeneously in normally perfused myocardium, whereas ischemic or infarcted areas appear blank (scintigraphic defects). The use of repeat imaging after 2–5 h enables the defects to be divided into exercise induced ischaemia and infarcted myocardium i.e. those in which the defects persist. A newer technique uses re-injection of thallium-201 three to four hours after the initial administration of the radio-isotope(16).

Because thallium has a low energy gamma ray (80 KeV) scatter is introduced into the images, lowering their spatial resolution. Also, as thallium is distributed throughout the body there is background activity interfering with the cardiac images and producing lower contrast. Thus the interpretation of the images require expertise assisted by computer smoothing for relative quantification of circumference profiles and washout rates. Gating of the thallium images to the electrocardiographic signal can overcome motion artefact and improve spatial resolution. However this increases imaging time. Despite the above problems, thallium imaging is used to clarify equivocal exercise tests and to predict prognosis in coronary disease.

As the technique of thallium perfusion is commonly used in conjunction with exercise electrocardiography, it is therefore an additional cost. A study by Kotler and Diamond(17) queried the level of incremental prognostic information provided by a thallium test above that given by history taking, a clinical examination, an electrocardiogram and a chest radiograph. The study found that the sensitivity (84 per cent) and specificity (78 per cent) for thallium testing were higher than for exercise electrocardiography. However, it was noted that selection bias may have exaggerated the diagnostic value of thallium scintigraphy by the inclusion of patients with a very high probability of disease.

A recent review of the use of thallium-201 concluded that, in clinical practice, the diagnostic value of thallium scintigraphy is almost certainly lower than the reported figures and is critically dependent on the prevalence of disease in the population tested. The conclusion was drawn that, apart from those patients in which the presence of repolarisation abnormalities is likely to impair the interpretation of an electrocardiogram, any case for extending the availability of thallium scintigraphy for the investigation of coronary artery disease cannot yet be sustained(18).

As regards accuracy in diagnosis of coronary artery disease, Rickenbacher et al.(19) note that the performance of thallium-201 myocardial perfusion imaging ranges from 80 per cent to 85 per cent (sensitivity) and 85 to 90 per cent (specificity) with similar values for SPECT thallium-201 imaging. The authors note that detection and localising of specific vessel disease appears to be improved with SPECT imaging. They also caution of the need for comparisons between different techniques to be performed on the same patients in order to avoid differences due to patient selection and exercise protocol. Also a thallium-201 reinjection technique is noted which is used to diagnose partly scarred but still viable myocardium.

Apart from screening for suspected CAD, thallium-201 imaging studies are used for predicting future events in patients after myocardial infarction. Pohost and Henzlova(20) consider that thallium-201 has an important role in predicting the risk of cardiovascular morbidity and mortality. Noting that the more extensive the area with reduced perfusion, the higher the risk of cardiovascular disease, they state that the thallium-201 study is at least as predictive of this risk as the number of diseased vessels determined by coronary angiography. However, they note that to produce reliable results, the technique requires considerable knowledge of both the kinetics of thallium-201 and the psychologic and clinical factors that alter them.

The introduction of single photon emission tomography (SPECT), a three dimensional imaging technique, has been designed to overcome the limitations of planar imaging[21]. As spatial resolution of SPECT thallium images is often low, better resolution can be achieved with newer technetium-99m labelled perfusion agents such as methoxyisobutylisonitrile (MIBI), in part because of higher count density[22]. The myocardial clearance of MIBI is very slow so that imaging is not dependent on time of injection. Also, it is possible to assess myocardial perfusion and function with a single injection[23].

Thallium-201 perfusion imaging is also used to assess the outcome of revascularisation procedures such as CABG and PTCA. In conjunction with exercise tests, radionuclide studies can be used to examine ischemic changes and to assess the heart rate and blood pressure response to exercise as well as ECG changes. However, nuclear medicine studies should be regarded as unnecessary where exercise ECG tests would be sufficient. Debate of the accuracy of myocardial perfusion scans continues and the risk of false positive diagnosis remains.

Usage—nuclear medicine

There is a variation between use of nuclear medicine perfusion studies on non in-patients across States in Australia when compared to the use of coronary angiographic studies (Table 1). Given the apparently higher morbidity associated with catheterisation, it could be expected that the less-invasive isotope studies might be preferred. Differences in utilisation may relate to the relative influence of radiologists and nuclear medicine physicians in each location. Although nuclear medicine investigations are normally performed by physicians, the RACR regards the modality as part of medical imaging. However, ANZAPNM requires that a qualified radiologist undergoes a further two years experience in an accredited nuclear medicine department before being allowed to practice nuclear medicine. Also a radiologist needs to obtain a licence to use isotopes from the Radiological Advisory Council in the State where he or she wishes to practice.

Although the College of Physicians does not conduct examinations in nuclear medicine, it does not recognise the nuclear medicine components of the RACR examinations. NSQAC now recognises nuclear medicine as a sectional specialty of diagnostic radiology. As well as requiring a practitioner to hold a licence to use radionuclides, it also requires a new trainee to undertake a two year training period in a nuclear medicine department. It also recognises radiologists who have had at least five years experience in providing nuclear medicine services and who are licensed to use radionuclides.

In the opinion of Schubert[24] there is a very uneven distribution of nuclear medicine services in Australia and few radiologists are likely to undergo two years training in nuclear medicine in isolation from the diagnostic modalities. He notes a need for the RACR to consider accreditation of nuclear medicine departments in departments of radiology, with six months training for radiologists who wish to practice the medical imaging and examinations such as those conducted by ASUM.

The availability and use of nuclear medicine services is partly determined by professional regulation and this may explain to some degree the variation in the use of services. From the basic data on services in Table 3 it appears that exercise ECG tests are used widely (123,000) whereas nuclear medicine tests are used less (22,000). However, of the nuclear medicine tests it is not known how many are used in conjunction with exercise ECG for screening for suspected CAD and what proportion are used for the management of proven CHD and for follow-up after revascularisation surgery.

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Echocardiography

Echocardiography is an effective, inexpensive non-invasive method of cardiac diagnostic imaging. The HIC data base recorded some 78,000 M-Mode examinations during 1990–91 at a cost of some $10.4m (excluding hospital in-patient examinations) and this increased to 103,000 in 1991–92 at a cost of $13.7m.

Since Hertz and Edler demonstrated the relationships between ultrasonic echoes and the structure and function of the heart in the 1950s, there have been a number of significant developments in the modality. M-Mode (time-position) recording has been widely accepted to study structure motion, and real-time two-dimensional imaging has been achieved with either mechanical scanning or electronically controlled phased array transducers.

As blood flow can be detected by the Doppler effect, the use of wide and narrow beams (duplex scanning) has introduced two-dimensional real-time imaging for volume localisation. The addition of colour coding has allowed the visualisation of regurgitant blood flow. Also the introduction of endoscopic (transesophageal) scanning can eliminate problems due to bone and gas artefacts. Finally the introduction of contrast agents (gas bubbles enclosed in soluble microspheres) allows the detection of small intracardiac shunts and valvular leaks as well as the assessment of perfusion defects(25).

Although echocardiography is relatively inexpensive and is capable of providing information in pediatric, congenital and valvular heart disease, it cannot adequately visualise the coronary arteries. As ischemic heart disease is a common form of symptoms for cardiac diagnostic investigation, exercise ECG and thallium stress testing are most frequently used in this area. These tests, although relatively expensive, avoid the need for coronary angiography with its associated morbidity.

Typically, echocardiography is used as a low cost non-invasive method of performing such tasks as the measurement of left ventricular wall thickness. For later analysis a continuous hard copy recording of the M-Mode display can be obtained to allow quantitation of cardiac structure motion in terms of amplitude and velocity.

An advantage of echocardiography is that it allows real-time two-dimensional scanning which can then be stored digitally for analysis by either single frame or cine replay. As well, the ECG signal is usually recorded for time correlation to assist interpretation.

The evaluation of the mitral valve is performed by Doppler echocardiography which simplifies the assessment of patients in the clinical setting. It can also be used to evaluate prosthetic valves non-invasively in the follow-up of these patients for stenosis(26). The investigation of mitral regurgitation by echocardiography has been helpful in differentiating between rheumatic and non-rheumatic valvular disease, left ventricular dysfunction and mitral valve prolapse(27).

The introduction of Doppler echocardiography has improved the non-invasive evaluation of valvular regurgitation. A number of studies have shown that pulsed Doppler correlates closely with left ventriculography in the detection of mitral regurgitation(28). Real-time two dimensional colour flow mapping allows non-invasive visualisation of intracardiac flow velocities. The size of the regurgitant colour flow jet correlates with angiographic severity of the regurgitation. Helmcke et al.(29) compared colour flow imaging with cardiac catheterisation in 47 patients finding that the sensitivity and specificity of colour flow Doppler from the detection of mitral regurgitation was 100 per cent.

Transesophageal echocardiography (TE) allows visualisation of the posterior structures of the heart. Image quality is improved by avoiding reflections from lung tissue or ribs. As TE is sensitive to the detection of mitral regurgitation, it has been used to evaluate the results of mitral valve repair intraoperatively[30]. Pulsed-Doppler echocardiography has been used to assess the velocities of pulmonary vein flow in the evaluation of mitral regurgitation severity, but are subject to a type of signal distortion called "aliasing".

Daniel et al have noted that abscesses complicating infective endocarditis have been found in 30 per cent of cases and are associated with a more severe course of the disease. Studies with transesophageal echocardiography have shown increased diagnostic accuracy over transthoracic echocardiography and lead to an improvement in the diagnosis of abscesses associated with endocarditis. TE facilitates the identification of patients with endocarditis who have an increased risk of death and permits earlier treatment[31]. However, Pearlman[32], in providing a summary of the applications of electrocardiography, has noted that TE is invasive and has risks (bleeding, bronchospasm) and overall would only replace transthoracic echocardiography in some 20 per cent of cases. TE is also being used routinely to monitor left ventricular performance before and after surgical intervention, for example in saphenous vein coronary bypass grafting.

An overview of the use of echocardiography of valve disease has been provided by Wilde[33]. The author concludes that the modality provides a reliable and non-invasive approach to the assessment of cardiac valve disease as well as providing insight into cardiac valve hemodynamics. It is noted that the modality can be substituted for cardiac catheterisation and can be repeated as often as necessary to monitor progress of either disease or treatment. A major advantage of the technique is that surgery can be undertaken in neonates and infants without the need for cardiac catheterisation.

However, because of the great variety of transducers and investigational approaches, the use of real-time echocardiography is subject to wide intra-observer and inter-observer reliability and the technique requires the development of great skills in qualitative interpretation of real-time images. This factor may be offset by the low cost and non-invasive nature of the technology.

A recent overview of the role of ultrasonic imaging of the heart was performed by the American Medical Association Council on Scientific Affairs[34].

In relation to coronary artery disease, the report noted that echocardiography was useful in examining patients with regional wall motion abnormalities at rest or following exercise. The report stated that two dimensional echocardiography has been shown to be as reliable as cineventriculography for the detection of wall motion abnormalities. Stress two dimensional echocardiography showed similar results to radionuclide methods in the identification of the presence and severity of regional wall motion abnormalities. The report noted that ultrasound does not require special licensing (as do radionuclide-based methods) and is generally less expensive than isotope-based approaches.

The report noted that there are no data to indicate that echocardiography is a reliable method for the detection and assessment of the severity of coronary artery disease in adults. However, the statement was made that echocardiographic methods are now the procedure of choice in the identification of complications of myocardial infarction such as aneurysm, thrombus formation and rupture of the interventricular septum. Combined with Doppler methods the precise location and extent of anatomic and flow disruption may be reliably and quickly determined.

Echocardiography was seen as the principal method for the evaluation of patients with valvular heart disease. When valve repair rather than valve replacement is considered, echocardiography alone can inform clinical decisions, providing information concerning the coronary arteries is not required. The status of valve prosthesis can also be evaluated.

The report noted that Doppler echocardiography is so sensitive to minor degrees of valvular insufficiency that a new definition of "normal" has been required as small degrees of valvular regurgitation may be found in apparently healthy individuals with no evidence of heart murmur on physical examination.

Pediatric and neonatal cardiology have come to rely on echocardiography for the detection of congenital heart disease. Doppler visualisation of the aortic arch in newborns has aided the non-invasive diagnosis of coarctation of the aorta. Colour flow mapping assists the evaluation of complex multilevel or bi-directional shunting patterns.

The bedside nature of portable echocardiography systems allows the evaluation of congenital heart disorders in children preoperatively and post-operatively, although adults are more difficult to image.

Two dimensional echocardiography is now established as the method of choice for the detection of pericardial effusion. It is possible to identify cardiac tamponade as well as to differentiate pericardial constriction from restrictive abnormalities. Echocardiography can also be used to identify patients with dilated and poorly contractile left ventricles and to monitor the ventricular response to drug therapy.

The advent of high resolution B-scan real-time imaging has led to diagnosis of fetal heart disorders. Fetal echocardiography is now a specialised area of ultrasonography. Miniaturised phased-array transducers should aid intraoperative, esophageal and intraluminal applications.

The report concluded that the availability of adequate echographic and Doppler data may eliminate the need for catheterisation in patients with congenital and valvular heart disease. However, for patients with suspected or known coronary artery disease, coronary angiography is required if surgical intervention is anticipated.

McDonald(35) has noted that M-Mode recording can provide information on left ventricular stroke volume and of myocardial contraction; however, such estimates are valid only in the absence of localised (ischaemic) left ventricular damage. McDonald et al.(36) considered that because echocardiography was a non-invasive test, its overuse could generate false positive findings which would cause long term anxiety to patients. Although echocardiography almost always provides some diagnostic information when the presence of heart disease is in doubt, the proportion of patients in whom management is altered is relatively low. Hence, thought should be given to likely impact on patient management before ordering echocardiography. Anxiety may be generated by the identification of untreatable but latent disease. This may result in disease labelling and further investigations which are costly to both patient and community.

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Coronary angiography

Coronary angiography is considered the reference standard for assessment of anatomic changes within the coronary arteries. Due to the limitations of other imaging modalities in visualising the coronary arteries, coronary angiography remains the preferred method for this task. Although it is an invasive imaging procedure involving the insertion of a catheter into the femoral artery, the guiding of the catheter to the coronary artery under fluoroscopic control and the injection of contrast material, it is a relatively safe procedure involving low morbidity and can be repeated if required.

Despite the statement by Gibson[37] that virtually every cardiac diagnosis previously made by cardiac catheterisation can now be made non-invasively, the use of the invasive test, coronary angiography, continues to increase for the diagnosis, therapy and monitoring of cardiac disease.

The preference of cardiologists and cardiac surgeons would appear to be for pre-surgical diagnosis to be confirmed by coronary angiography. Given the rise in the numbers of PTCA and CABG procedures in Australia and the increasing age of the population, it could be assumed that the use of cardiac catheterisation for both pre surgical and post surgical monitoring will continue to rise.

Improvements in coronary angiography, particularly the use of Intra Arterial Digital Substraction Angiography (IA DSA), in which the tissue background is subtracted to leave an enhanced contrast image, have increased the range of applications. The digital image makes possible quantitive measurement of cardiac function and is suitable for image enhancement. However, because of the difficulties of cardiac and respiratory gating involved in matching images prior to subtraction, there may be a loss of image resolution. However, a major advantage of DSA is the reduced need for the volume of contrast required for imaging.

A typical application of IA DSA was reported by Boonstra et al.[38] when investigating the use of IA DSA as a screening method to visualise graft patency after CABG. They noted that the patency of the grafts was adequately visualised in 68 of 71 patients by means of DSA and concluded that the procedure could be performed safely on an outpatient basis.

Intra Venous DSA (IV DSA) held promise for visualising the left heart and aorta. Although it is possible to obtain left ventricular angiograms, the use of contrast obscures the origins of the coronary arteries, preventing the exclusion of significant disease. As well IV DSA requires large volumes of contrast which may aggravate heart failure in susceptible patients.

Cine angiography offers high temporal resolution being capable of recording up to 90 frames per second. This feature has application in pediatric coronary studies allowing the visualisation of valve movements in real time. Digital storage techniques now allow the storage and review of digital images on either optical disc or digital tape drives, thus removing the delays previously associated with processing of film.

One of the problems with assessment of imaging modalities is the degree of substitution. For example, coronary angiography, radionuclide techniques and echocardiography may be used for the assessment of left ventricular function in postoperative control of patients with coronary artery by-pass grafts. Given the problems of inter-observer variability with coronary angiography, echocardiography would appear to be less invasive and gated blood pool scans less expensive. The selection of an imaging modality therefore depends on the preference of the physician and familiarity with a particular modality.

Considerable experimental rigour needs to be employed to avoid the difficulties of inter-observer variation in interpreting coronary angiograms as demonstrated in a report by Ornish et al.[39]. The study was designed to measure regression in stenosis in coronary artery lesions associated with coronary atherosclerosis over a period of one year. A baseline coronary angiography study was performed during which orthogonal views were obtained and the angle, skew, table height and type of catheter used were recorded. One year later, follow-up angiograms were taken which were identical in their view angles, their sequence, type of contrast dye, the angiographer and the cine arteriography equipment. Catheter tips were saved and used as reference measures for quantitative analysis which was performed using a standardised protocol at a reference laboratory.

Given the variety of techniques available for cardiac imaging, the question becomes one of appropriate patient selection. An audit by Gray et al.[40] in the United Kingdom reported that 21 per cent of coronary angiographies were deemed inappropriate. The report concluded that audit by predetermined consensus criteria (appropriateness scores) may help to determine which patients should first be investigated when resources are limited. The report qualified the findings by noting that an investigation considered inappropriate by the standards laid down by a review panel does not necessarily mean that the decision made by the clinician who managed the patient was incorrect. Some 30 per cent of the patients in whom coronary angiography was considered "inappropriate" were found to need coronary artery by-pass surgery.

The standards applied in the United Kingdom for acceptable practice vary from those used in Australia. However, the criteria of "appropriateness", i.e. when the expected benefit to health in terms of increased life expectancy, symptom relief or improved function exceeds the potential mortality or morbidity of the procedure, should have universal application. The cost implications of audits such as that by Gray et al. are significant. Assuming some 30,000–40,000 coronary angiograms are performed in Australia each year a reduction of 20 per cent would represent a saving of approximately $3m per year and associated reduction in morbidity for a large number of patients.

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Magnetic resonance imaging (MRI)

At present, MRI of the heart is not indicated as a routine diagnostic test as it is unable to produce equal or better diagnostic and management results than other existing tests. There is a shortage of outcome data associated with MRI examinations. As yet there are no reliable cost data on use of MRI in cardiac applications, but MRI costs would probably be high and additional to that of other investigations. Although there is a great deal of overseas research being conducted on the use of MRI in the heart, as yet there are no consensus in Australia on the role of MRI as a complementary cardiac diagnostic technology.

Current MRI reseach areas include:

- **Coronary artery disease**

In assessing the sequelae of coronary artery disease, MRI provides direct visualisation of the myocardium. It has defined segmental wall motion or wall thinning and shown secondary changes caused by myocardial infarction, such as mural thrombus, aneurysm or wall rupture[(41)]. However, the above advantages, the limitation of MRI in coronary artery disease is the inability to visualise the coronary arteries. This would require significantly improved spatial resolution to allow MRI to compete with established imaging modalities such as nuclear medicine and selective coronary arteriography.

- **Evaluation of right ventricular function**

Demonstration of the right ventricle and assessment of right ventricular function is difficult with most imaging techniques, including echocardiography, radionuclide ventriculography, and angiography. MRI offers the possibility to image the right ventricle in multiple imaging planes throughout the cardiac cycle[(42)].

- **Detection of atheroma**

A feature of MR imaging is the ability to detect atheroma. It is important to know if atheromatous plaque is at an early stage and reversible or whether it is infiltrated with lipids, scarred and irreversible. Such classification can be performed by using magnetic resonance techniques which highlight fat or water. The read gradient can be centred so that it will detect one or the other and subtraction of the fat and water images shows the amount of tissue which contains a mixture of both.

Longmore has suggested that such techniques might be used for the screening of patients in a non-invasive manner, thus avoiding the morbidity of angiographic catheterisation[(43)].

- **Congenital heart disease**

MRI is emerging as a non-invasive imaging technique for the diagnosis and management of patients with congenital heart disease. Previously cardiac imaging was based on radiography and fluroscopy with cardiac catheterisation and angiography being used for a precise evaluation of cardiac anatomy and hemodynamics. MRI can now provide depiction of cardiovascular anatomy in congenital heart disease, particularly in newborn infants where non-invasive methods of investigation are preferred.

MRI must compete with the more well established technique of two dimensional echocardiography. Indeed, advances in engineering and the development of high-resolution imaging colour-flow Doppler mapping, continuous wave Doppler, and other ultrasound techniques have established that surgery can be undertaken in some instances based on the clinical examination and the echocardiogram[(44)].

It appears that MRI will play a role in examining patients with congenital heart disease, including evaluation of intracardiac shunts, determinations of relative position of outflow vessels and postoperative evaluation of patency of shunts after repair. However studies are necessary to compare the relative clinical efficacy of MRI with less expensive techniques. The two major potential advantages of MRI are the lack of interference from bone or lung (as experienced with echocardiography) and the ability to conduct non-invasive angiographies due to the contrast provided by the motion of blood.

- **Cine MRI**

Cine magnetic resonance imaging is a technique that provides segmentation of the cardiac cycle into a sufficient number of images so that ventricular function can be assessed. Because of variations in the signal of flowing blood in relation to velocity and flow profile, flow disturbances have been recognised[45].

The technique extends the ability of MRI beyond anatomical diagnoses to quantitation of ventricular function and valvular function as well as anomalous blood flow patterns. The blood pool generates high signal intensity on cine MR images under normal conditions. Abnormal flow is recognised as a loss of signal within the blood pool.

As it is a non-invasive technique it can be used for the sequential monitoring of ventricular function over time. However, the role of a relatively expensive imaging technique in relation to two dimensional echocardiography, echo Doppler and colour flow mapping is uncertain.

- **Combination of SPECT and MRI images of the heart**

It is not unusual for a number of tests to be performed in a single patient for cardiac examination so that the heart is shown in different orientations. The difficulty of this approach is that the consulting physician then has to integrate the images which may be acquired at different scale factors.

Image registration is a technique described by Faber et al.[46] to integrate a number of studies such as a MR image of left ventricular structure and SPECT data on myocardial perfusion. When the two images are registered, the exact anatomic location of a perfusion abnormality can be identified and the effects of the abnormality on motion and thickening can be observed. Registration is performed by using the boundaries of the endocardial surface. After registration, the two images can be combined; the image contains the brightness of the original MR signal and the colour of the SPECT signal.

Important data from two images are displayed in one image. The displays show the relationship between perfusion from SPECT images and myocardial thickness, motion and thickening from MR images. Further developments are possible such that SPECT information about myocardial metabolism and MR images showing the location of scar tissue could be registered.

- **Use of contrast agents in MRI cardiac imaging**

Contrast agents which define the relative intensities of two adjacent regions, when used in conjunction with MRI can assist in the assessment of tissue function and the improvement of morphological definition. Paramagnetically labelled macromolecules are used with MRI because of their intravascular distribution which may have benefits in assessment of tissue vascularity, tissue blood volume, endothelial integrity and relative perfusion.

The relative accumulation of contrast media, assessed qualitatively is of major diagnostic value in radiological investigations. Relative tissue accumulation of intravascular MR contrast media could be useful to identify areas of abnormal perfusion, as is already performed with thallium isotope imaging.

Brasch et al studied the use of MR contrast enhancement of irreversible ischemia producing acute myocardial infarction in animals using albumin-(Gd-DTPA)[47]. The study noted that with the use of albumin-(Gd-DTPA) myocardial ischemia can be detected as early as three minutes after the occlusion of the left coronary artery and can be differentiated from normally perfused myocardium. The study provided encouraging results and suggested further studies of macromolecular Gd-based contrast media[48]. While it may be some time before these materials become available in Australia there is the potential for a range of MR contrast agents to emerge whose claims will need to be assessed if MRI application to cardiovascular imaging becomes widespread.

In summary while MRI appears to offer promise in a number of areas of cardiac investigation, there will be a need for controlled trials to demonstrate the place of a new and expensive diagnostic modelity and its relationship to existing tests.

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Cine CT—(dynamic CT)

Proponents of Cine-CT (Imatron scanner C–100) claimed in 1989 that electron-beam systems would not only replace fourth generation CT scanners but might become a complementary or even the primary screening and diagnostic cardiac imaging technique of the future[49].

These above assertions were based on the fact that previous CT scanners using long exposure times (over 1 second) produced blurred images of the heart, whereas electron beam technology could perform 50 ms scans at frame rates of up to 34 images per second. The Cine-CT system has no moving parts except for the patient table which can be angled depending on the region of cardiac anatomy to be imaged.

The technique of dynamic CT has been developed over the past ten years[50]. It has not yet been introduced into Australia. As with any new technology, controlled clinical studies are necessary to validate the performance of Cine-CT compared with established angiographic, echocardiographic and nuclear medicine imaging techniques. A non-ionic contrast agent is essential for quantitative CT studies, and this potential risk factor must be taken into account. Advantages of Cine CT is that it is a fully three dimensional method of cardiac investigation and is not subject to the risks, complications and technical limitations of selective angiography and digital subtraction angiography. As well, the technology can demonstrate anatomic structures in any plane in real time movie format and is capable of measuring myocardial perfusion[51, 52].

Although the potential of Cine CT has been recognised in cardiac imaging, particularly in screening for calcification of the coronary arteries when compared to fluoroscopy, developments in fourth generation CT have tended to overshadow Cine CT. Breath-holding techniques, along with sub-second scans, enable 24/32 slices of the cardiac cycle to be obtained by fourth generation CT in under 16 seconds, giving freeze frame depiction of coronary anatomy. MRI cardiac angiography has shown promise and does not require use of a contrast agent or expose the patient to ionising radiation.

The unique maintenance, siting and air-conditioning requirements for Cine CT using vacuum technology, along with capital costs, have tended to deter potential users. The advantages of fourth generation slip-ring CT ($1.4m) means that, despite the fact that some twenty Imatron Cine CT systems have been installed world-wide, it is unlikely that this technology will contribute to developments in cardiac imaging in Australia.

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Positron emission tomography (PET)

PET imaging makes use of short lived positron emitting isotopes in the body. Compared with the more widely used single photon emitting tracers, such as thallium-201 and technetium-99m, positron emitting tracers offer the advantage of more accurate 3D reconstruction of the tracer distribution within the body. They also allow precise regional quantification of the tracer.

Previously thallium scintigraphy has been used to delineate viable from non-viable myocardium. The use of PET in the prospective delineation of viable and non-viable myocardium has been proposed, based on patterns of myocardial perfusion and metabolism[53].

PET imaging has been used for the measurement of transient myocardial ischemia. Although the aerobic myocardium normally uses free fatty acids for producing energy, during ischemia glucose becomes the most important substrate to maintain energy production. PET scanning represents a tool for the measurement of the regional uptake of glucose, or of its analogue deoxyglucose, in the areas of the myocardium which were caused to switch to glycolytic metabolism by ischemia.

PET employs a two step approach to the evaluation of myocardial viability i.e. the reversible impairment of regional myocardial contractile function. Tracers of blood flow identify hypoperfused myocardium which is then examined by uptake of fluorine-18-fluorodeoxyglucose (FDG) for residual metabolic activity to determine if contractile function will improve once blood flow has been restored. Regional myocardial perfusion is evaluated with PET at rest, unlike stress scintigraphy with thallium or technetium-labeled perfusion imaging agents.

As ischemia induces changes in metabolism in areas of the myocardium which show reduced contractile function, enhanced uptake of fluorine-18-fluorodeoxyglucose (FDG) in relation to flow has been proposed as an accurate means to identify viable myocardium[54]. The regional distribution of FDG, assessed 40–60 minutes after administration of a tracer is thought to reflect overall glycolytic flux[55]. Studies of patients with coronary artery disease have suggested that the use of PET with FDG can identify viable myocardium in areas of contractile dysfunction. In patients with stable coronary artery disease, improvement in regional function after revascularisation was evident in 75–85 per cent of dysfunctional segments that exhibited FDG accumulation. In contrast, between 78–92 per cent of segments with diminished flow and concomitantly reduced FDG uptake failed to exhibit functional improvement after surgery[53].

The clinical question addressed by PET is whether the contractile dysfunction is reversible, i.e. will contractile function improve if blood flow is restored. In myocardial "stunning" relief of ischemia may be provided by restoration of myocardial blood flow. It is seen as clinically important to differentiate this condition from irreversible loss of contractile function resulting from necrosis and scar tissue formation when selecting patients for revascularisation.

The claim for PET imaging is that it is possible to predict the post interventional outcome of global left ventricular function after surgical revascularisation[56]. Thus, if large myocardial regions with reversible dysfunction are demonstrated in PET, then surgical revascularisation is likely to result in significant improvement in left ventricular function and in amelioration of congestive heart failure symptoms.

A further use of PET is to determine if patients with ischemic cardiomyopathies are suitable for coronary artery by-pass surgery as opposed to cardiac transplantation. A group at UCLA has reported the use of metabolic imaging with PET to detect viable myocardium in patients with severe congestive heart and triple-vessel coronary artery disease failure referred for cardiac transplantation[57]. Given the short supply of donor organs potential cost savings can be accrued by streaming patients for either CABG or transplantation.

In the past, stress thallium-201 imaging has been used for identifying reversible ischemic myocardium. In a comparative study of thallium imaging with FDG-PET scan, more than 40 per cent of the segments showing fixed defect without redistribution on a thallium scan showed persistent metabolic activity on FDG-PET[58]. Although a reinjection technique for thallium has been developed (Section 3.2), Tamaki et al.[59] have reported that FDG-PET remains superior for assessing tissue viability, mainly because FDG can detect viable myocardium in the areas with reduced perfusion under resting conditions.

Given the emergence of dual-injection thallium scintigraphy techniques, there remains a need for a prospective comparison of Tl-201 and FDG-PET for assessment of myocardial viability in patients with ischemic cardiomyopathy.

As with other new high cost imaging techniques, further economic and technical analysis would be desirable to establish the place of PET in the Australian health care system.

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