Imaging of the Heart

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Most people from time to time become aware of the regular or irregular beat of the heart. As this is often during moments of high emotion or stress, the heart has featured greatly in popular culture and the arts. It is widely mentioned in poetry and literature. In the 1989 Oxford Dictionary of Quotations references to the heart far exceed those to lung, brain, liver or spleen. Endocrinologists will note with dismay the complete absence of quotable remarks about pituitary, thyroid or pancreas.

An Egyptian papyrus from the 16th century BC - now in a museum in Brussels - shows one of the earliest visual representations of the heart. The heart was thought to represent conscience; after death it was placed in scales. If it proved heavier than a statue of truth the signs were thought favourable; and the fortunate deceased was led towards Osiris rather than to the nether regions. Where there was doubt about the probity of the dead man, the odds could be improved by using an ostrich feather instead of the statue. The heart seems less than impressive in the papyrus, but perhaps something has been lost by the passage of 3,500 years and by the quality of reproduction.

In medical texts of the middle ages representations of the heart and circulation were also somewhat fanciful. More anatomically accurate pictures were to follow with the work of Vesalius, Leonardo da Vinci and others during the 16th century. By the 19th century the morbid anatomy of cardiac disease was well established, but it was not until this century that it became possible to look at the beating heart in vivo.

At the time I started cardiology in 1971, diagnosis was made by a combination of clinical symptoms and signs, the electrocardiogram, the chest X Ray and in highly selected cases information from cardiac catheterisation and angiocardiography. In the last 25 years minimally invasive techniques of viewing the heart have become available. Tables 2 and 3 indicate some of the relative merits of 3 techniques discussed in this paper.

\[\text{TABLE 1}\]

| Organ     | Quotations |
|-----------|------------|
| Heart     | 227        |
| Brain     | 25         |
| Liver     | 6          |
| Lungs     | 5          |
| Spleen    | 2          |
| Pancreas  | }          |
| Pituitary | }          |
| Thyroid   | 0          |

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\[\text{TABLE 2}\]

| Feature               | Ultrasound | Technique Radio Nuclear | MRI |
|-----------------------|------------|-------------------------|-----|
| Safety                | +++        | +++                     | +++ |
| Expense               | +          | +                       | +++ |
| Bed side Studies      | +++        | +                       | 0   |
| Time for study        | +          | +                       | +++ |
| Operator Skills       | +++        | +++                     | +++ |
| Possible in all       |            |                         |     |
| Patients              | +          | +++                     | +++ |
| Convenience           | +++        | +++                     | ++  |

(Each feature is gauged on a scale of 0 - ++++: for example in terms of convenience, ultrasound is straightforward, MRI (Magnetic Resonance Imaging) is relatively inconvenient)

ECHOCARDIOGRAPHY

Echocardiography has probably been the most widely available of these techniques and the one which has made the greatest impact on the practice of cardiology. The first cardiac ultrasound pictures in man were published by Edler in 1954, but it was not until the 1970's that echo techniques became widespread in clinical cardiology. Ultrasound is entirely safe, and its high temporal resolution permits beat to beat analysis of the heart.

Developments in technology allowed the progression

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TABLE 3

| Feature          | Technique Ultrasound | Technique Radio Nuclear | Technique MRI |
|------------------|----------------------|-------------------------|---------------|
| Ischaemic        | +++                  | ++++                    | ++            |
| Valve            | ++++                 | ++                      | +++           |
| Congenital       | ++++                 | +                       | +++           |
| Cardiomyopathy   | ++++                 | ++                      | +++           |
| Pericardial      | +++                  | 0                       | +++           |
| Endocarditis     | ++++                 | 0                       | ++            |
| Tumours          | ++++                 | 0                       | ++++          |

(Adapted from: Heart Disease: Edited by E. Braunwald)

from single to two dimensional images; these were later complemented by Doppler wave form analysis and colour display. Doppler techniques add the ability to look at blood flow within the central circulation. In 1980 Hatle and co-workers described the simple modified Bernoulli equation:

\[
\text{Pressure difference (mmHg)} = 4 \times \text{peak velocity (m.sec}^{-1}\text{)}^2,
\]

allowing the conversion of velocity measurements into pressure. With colour coding of Doppler signals it is possible to detect and partially quantify abnormal valvular regurgitation or shunt. A transoesophageal approach allows high quality images to be obtained of structures relatively invisible to a probe on the anterior chest wall.

Echocardiography has resulted in a greatly improved ability to diagnose and understand a whole range of clinical conditions including congenital heart disease, pericardial disease, ventricular size and function and the cardiomyopathies. In the field of adult cardiology the assessment of valvular disease has been of great importance. For example, in a patient with rheumatic valvular disease it is possible to assess mitral and aortic valve areas, the degree of regurgitation through each valve, chamber size and function, and obtain information about intra-cardiac pressures. Such a complete picture results that it is often possible to avoid invasive evaluation. Recent developments include the use of stress echocardiography to diagnose and guide management of the patient with coronary artery disease, and intra-vascular ultrasound catheters to aid coronary intervention by angioplasty and stents.

Echocardiography has some disadvantages - it is relatively time consuming to perform an examination, it requires a skilled operator and in some-patients it is simply not possible to get high quality images.

NUCLEAR CARDIOLOGY

Nuclear imaging of the heart overcomes some of these difficulties, though presents other methodological problems. The first camera suitable for medical imaging was designed by Anger in 1958, but as in the case of ultrasound, it was not until the 1970's that the technology began to make a major impact.

Two major uses have evolved; the assessment of ventricular function and the analysis of myocardial blood flow and perfusion. One of the great advantages of nuclear techniques is that the information is in digital form, and can be readily manipulated by computer to produce quantitative information. For example, left ventricular ejection fraction - a measure of left ventricular function - can be calculated with ease. Digital imaging also permits tomographic reconstruction - this is now used routinely in many centres in the assessment of perfusion.

Ventricular Function

The most widely used technique is that of blood pool imaging. An isotope (usually 99m technetium) is tagged on to an intravascular structure (red cell or albumen). Because, during each cardiac cycle the heart will contain only a small amount of isotope, the technique of gating was developed - with this, acquisition of data is synchronised to the R wave of the ECG. The data from successive cardiac cycles are summed, the starting point being each R wave - at the end of the study, a composite or average heart beat is obtained containing information from perhaps up to 300 cycles.

The ejection fraction is calculated from the isotopic activity (scintillations counted) within the final images after correction for 'contamination' from background structures using the formula:

\[
\text{Ejection fraction} = \frac{\text{End diastolic} - \text{end systolic activity}}{\text{End diastolic activity}}
\]

Function may be assessed from the passage of a bolus of isotope through the heart - first pass imaging. During its transit through each chamber it is possible to make an estimate of function.

We have been fortunate to have had the opportunity of investigating this technique using a novel imaging device - the multi-wire camera. This camera, different in concept from the traditional 'Anger' camera, may be used successfully with a low energy isotope.
(tantalum 178) which has also a short half life. High quality images may be obtained with a low radiation exposure for the patient. We have used this technique to study the response of the left ventricle to maximum stress in a wide range of clinical conditions including patients with recent myocardial infarction, heart failure and congenital heart disease.

By whatever method it is measured, radio-nuclide ejection fraction at rest of after stress is a powerful predictor of long term prognosis especially in patients with ischaemia heart disease. Data from the Mayo Clinic in patients with known or suggested coronary artery disease have shown that an exercise ejection fraction of less than 0.30 is associated with a cardiac event rate of almost 50% over a 4 year period.

**Perfusion Imaging**

Perfusion imaging of the myocardium was initially done with thallium - an analogue of potassium - but more recently technetium has been favoured because of its better imaging characteristics. Only metabolically active heart muscle will take up the isotope. The amount that is taken up is directly related to blood flow. Tissue that is dead or ischaemic and has a reduced blood supply (usually because of coronary artery disease) will acquire little isotope and will appear as an area of reduced activity.

In most perfusion scans the isotope is injected at peak exercise or after a pharmacological stress (dipyridamole, adenosine). The pictures that are obtained are then compared with a study at rest - either a second injection of the isotope at rest, or where thallium is used, a repeat series of pictures 4 hours after the first injection. Comparison of the 2 sets of images allows the areas of reduced uptake to be classified as fixed or transient defects. In general terms, the former are more likely to represent infarction, the latter ischaemic tissue.

When the technique was first described, the heart was in imaged in various 2 dimensional planes, this has been superseded in most centres by 3 dimensional tomographic reconstruction - so called SPECT (Single Photon Emission Computed Tomography). Analysis of the scans may be in a visual qualitative fashion, though interpretation of the data is often enhanced by quantitation of the results.

Perfusion imaging can aid the non-invasive diagnosis of coronary artery disease. Table 4 shows a summary of some of the studies in which perfusion imaging has been used to diagnose the presence of ischaemic heart disease. Quantitative planar imaging yields a sensitivity of 89% and a specificity of 68%. Improved results are obtained when SPECT imaging is used. The rather low specificity probably reflects referral bias. This is supported by the high normalcy rates for both methods.

Perfusion imaging may also help in the detection of viable myocardium. A non-contractile area of the heart may represent scar tissue of potentially viable muscle in a state of ‘hibernation’ - restoration of blood supply to a hibernating zone by by-pass surgery may allow return of muscle function. Detection of ‘hibernating’ tissue by nuclear and ultrasound methods has become an increasingly important issue in clinical cardiology.

**MAGNETIC RESONANCE IMAGING**

The technique which has most recently been applied to cardiology is that of Magnetic Resonance Imaging (MRI). Protons in a strong magnetic field are exposed to radiofrequency pulses. The protons subsequently emit a radiofrequency signal which can be detected. The first picture - a human finger - was obtained in 1976 and since then development has been rapid. The method allows high quality structural data as well as ‘cine’ sequences to be obtained - as in the case of nuclear cardiology, acquisition of a study may require ‘gating’ with the ECG.

In cardiology it has found application in the diagnosis of aortic aneurysms both dissecting and nondissecting and pericardial disease. Excellent pictures can also be obtained of cardiac tumours, regurgitant and stenotic lesions and chamber size and function. It is also possible to identify flow within coronary vessels though the quality is not as yet good enough to show coronary anatomy reliably. The exact place of MRI in imaging of the heart is still being evaluated.

| Method            | Sensitivity(%) | Specificity(%) | Normalcy(%) |
|-------------------|----------------|----------------|-------------|
| Perfusion Planar  | 89             | 68             | 88          |
| Perfusion SPECT   | 89             | 89             | 88          |

(Adapted from reference (8))

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FUTURE TRENDS

Predictions about the future direction of cardiac imaging remain guess work. Echocardiography will remain a valuable technique being relatively inexpensive, safe and quick. There will be continued improvements in image quality and 3-dimensional reconstruction of images. There are likely to be considerable advances in the assessment of myocardial perfusion especially with the use of contrast agents injected peripherally.

The long term future of nuclear methods in cardiology is perhaps less certain. Developments in echocardiography and MRI may take over some of the functions of the nuclear laboratory. However, it is likely that nuclear methods will remain as the most convenient for assessing myocardial perfusion and new isotopes should make determination of myocardial metabolism more readily available.

I suspect that over the next one or two decades there will be a great expansion in the use of MRI in cardiology. The noninvasive nature of the method, its safety, and the ability to reconstruct and quantify the data are all important features. At present the method is quite slow and may be difficult to perform in the acutely ill patient. In the years ahead, new methods of analysis, faster acquisition times and reduced cost will probably ensure a considerable expansion of cardiac MRI.

This has been of necessity a short and comparatively superficial survey of some of the developments in cardiac imaging over the last 30 years. Having the ability to perform accurate and reliable tests puts an onus on the clinician to use the investigations wisely - to order them appropriately and to interpret them correctly. In 1933, Sir Thomas Lewis wrote in the preface to his textbook of cardiology:

'It has been important to try to achieve a proper perspective of values so as not to place undue weight on this or that, because its novelty attracts or because it has a strong personal interest.'

In most cardiology units, including our own, there has been a major increase in the number of tests being requested, with an inevitable effect on waiting times and costs. Thus, since 1922, the number of ECGs performed each year has increased by 20% and the current waiting time has increased from 3 to 9 months. Not all of these tests may be necessary, and no test, however good, should be permitted to be a substitute for clinical judgement.

The same ‘proper perspective’ of Lewis is still required today.

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