Invasive investigations and revascularisation

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Invasive investigation of coronary artery disease is relatively expensive, and carries risks including a mortality of approximately 1 in 2000. It would not be practical or appropriate to perform invasive investigation in all patients with a clinical diagnosis of coronary artery disease, still less in the large numbers with chest pain and possible angina. Clinicians will refer for invasive investigation those: (i) with a high level of angina, needing revascularisation on symptomatic grounds; and (ii) who are likely to have a poor prognosis with medical treatment, and thus likely to benefit from revascularisation. Not all of these patients will have a high level of symptoms.

In the late 1950s and early 1960s, there were major advances in the treatment of coronary artery disease – the techniques of external cardiac massage, electrical cardioversion, and the introduction of lignocaine transformed the approach to acute myocardial infarction and arrhythmias, and led to coronary care units. At the same time, Sones and Judkins introduced methods of selective coronary arteriography, a prerequisite for coronary artery surgery. In the mid- and late-1960s, early forms of exercise ECG testing (Masters step test) and of isotope myocardial perfusion imaging (with caesium) were developed to identify those with severe coronary disease likely to benefit from coronary arteriography and revascularisation.

In the 1960s and 1970s, large registries charted the natural history of patients after their coronary artery disease had been defined by arteriography, and showed poor prognosis of those with triple vessel disease or left main stem disease. Randomised clinical trials of coronary artery surgery in the late 1970s and early 1980s showed that, for these groups of patients, surgery conferred prognostic benefit as well as symptomatic relief of angina. This established the value of coronary arteriography in deciding the correct treatment.

Invasive investigation is now taken to mean ‘left heart catheterisation’, comprising selective coronary arteriography with multiple views to show all major coronary vessels clearly without overlap or foreshortening, and contrast left ventriculography to show left ventricular function and any regional wall motion abnormality. It is used to assess the prognosis and hence need for revascularisation, as well as the anatomical (technical) suitability of the vessels for grafting or for angioplasty. In special circumstances, it may be used simply to confirm or refute the diagnosis of coronary artery disease, for example in airline pilots.

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**Prognostic assessment (risk stratification)**

Once the diagnosis of coronary artery disease has been made, it is important to assess the outlook to decide upon future treatment and the possible need for invasive investigation and revascularisation, as well as for the patient's information. The main determinants of prognosis are:

1. **Left ventricular function** – this is statistically the most powerful predictor not only in coronary artery disease, but also in cardiomyopathies, valvular heart disease, and many other conditions.

2. **The anatomical extent and severity of coronary artery disease** – as defined precisely by angiography, or as estimated by one of the non-invasive tests discussed in the preceding section.

3. **Recent unstable angina or acute myocardial infarction** – there is increased risk of death and of future infarction for at least 6 months following an acute coronary syndrome.

4. **General health** – co-morbidity such as diabetes, renal disease, pulmonary disease, and age.

Information may also be gained from the basic tests, such as the finding of pathological Q waves on the resting ECG, or noting a large heart and pulmonary venous congestion on the chest X-ray. Simple clinical risk scores have been devised, but they are not widely used in practice. Prediction is greatly strengthened by adding the results of a non-invasive test, for example the Duke exercise test treadmill score. At present, these too are little used in practice, but the spread of information technology in medicine may change this – scores can easily be calculated from data already entered into an electronic patient record, and presented to the clinician on the desktop for ‘decision support’.

Non-invasive testing has been discussed elsewhere in this issue, but we should make some general points. All the non-invasive tests are inaccurate to some degree. If we use coronary angiography as the gold standard to define the presence a stenosis of 50% or greater in a major epicardial vessel, then typically the sensitivity is 70–90% and specificity 70–90% for the above methodologies. Moreover, each method has specific weaknesses; for example, the treadmill exercise ECG is poor at reflecting disease in the circumflex territory. Interpretation of the exercise ECG is difficult if there is resting bundle branch block or other abnormality. CT coronary calcification scoring is only useful over the age range 40–70 years, as at younger ages there may be significant coronary plaques with little calcium. At ages over 70 years, there is often widespread coronary calcification irrespective of luminal narrowings. Stress echocardiography is perhaps the most operator-dependent technique and results will vary considerably according to the skill and experience of the echocardiographer obtaining and then interpreting the images, particularly at the high heart rates and...
respiratory movement associated with exercise or pharmacological stress. Myocardial perfusion scanning may have the highest predictive value, but involves a significant radiation dose to the patient. It is probably the investigation of choice if the patient is unable to exercise on a treadmill or cycle ergometer because of lower limb orthopaedic or vascular problems, or if there are resting ECG abnormalities.

If more than one non-invasive test is performed in a given patient, one test may give a result indicating normality and the other indicate coronary disease. When there are discrepant data, the clinician has to make a decision on the overall situation as to whether there is likely to be coronary artery disease or not. Performing additional tests is also of limited usefulness because of ‘predictive redundancy’ – the incremental information from performing a second non-invasive test is less than would be expected if they were independently predictive. Patients who have an equivocal test with one modality are more likely to have an equivocal test with another modality, and those who are false positives with one are also more likely to be false positive with another – the reasons for this are unclear, but it is of practical importance. If the most appropriate non-invasive test has been correctly selected for the individual patient, then if the result is borderline or does not fit with the clinical picture, performing another different non-invasive test may not be helpful. However, all of the non-invasive tests have considerable prognostic value, aside from their ability to detect structural coronary artery disease – this is discussed in the chapter by Underwood.

**Invasive investigation**

Selection of patients for left heart catheterisation for assessment of coronary artery disease can be summarised by the flow chart presented in Figure 1. This is greatly simplified, and in practice the correct decision for an individual patient will depend on many other factors, including patient preference, and co-morbidity. Across the world, local resources and availability of cardiac catheterisation will also affect referral for invasive investigation.

**Percutaneous coronary intervention**

Balloon angioplasty of the coronary arteries was introduced by Gruntzig in 1977, and the results were greatly improved by the introduction of coronary stenting by Sigwart and by Puel in 1986. The term ‘percutaneous coronary intervention’ is now taken to include balloon angioplasty, stenting, and occasional other technologies such as atherectomy and laser methods.
The indications for percutaneous coronary intervention (PCI) have evolved over the years, as the quality of the evidence has improved. The initial experience was based on ‘common sense’ – when balloon angioplasty was first introduced, it seemed sensible to treat simple lesions in patients with single vessel disease, or in patients who were unsuitable for coronary artery surgery because of co-morbidity. When coronary stenting was first introduced, it was only used for ‘bail-out’ to restore flow in lesions that had dissected or occluded during conventional balloon angioplasty.

In the 1980s, large registries began to provide firm (non-randomised) data on the short-term success rates, complications, and long-term outcomes\(^4\). These data informed clinicians and patients when choosing between medical therapy, coronary surgery, and PCI.

In the 1990s, randomised controlled trials started to appear comparing PCI with medical therapy, and PCI with surgical revascularisation. Trials such as BENESTENT and STRESS compared elective stenting with conventional balloon angioplasty. Other trials have addressed technical aspects of PCI such as the use of intravascular ultrasound to guide stent deployment, and the use of atherectomy devices, intravascular radiation to prevent re-stenosis, and adjuvant drug treatment with glycoprotein IIb/IIIa blockers and other drugs. As a result, there is now a large published literature on which recommendations and guidelines can be based.

A thorough digest of the evidence and of current recommendations has been published by the American College of Cardiology and the...
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Table 1  Indications for percutaneous coronary intervention (PCI) as proposed by the American College of Cardiology and the American Heart Association5

* Patients with mild angina or currently asymptomatic, if there are significant lesions in 1 or 2 coronary arteries subtending a large area of viable myocardium, who are not diabetic
* Patients with moderate or severe angina, if there are significant lesions in 1 or 2 coronary arteries subtending an area of viable myocardium
* Patients with moderate or severe angina and previous coronary bypass surgery, if there are significant lesions in vein grafts which are focal stenoses or multiple vein graft stenoses in patients who are poor candidates for repeat surgery
* Patients with acute myocardial infarction who have a contra-indication to thrombolytic therapy, and/or who develop cardiogenic shock within 36 h of the onset of infarction
* Patients with acute myocardial infarction who present early (within 12 h) may be considered for PCI as an alternative to thrombolysis, if local PCI is readily available
* Patients with acute myocardial infarction who have continuing pain and ST elevation despite thrombolysis

American Heart Association in a joint document5. These are summarised in Table 1.

Less certain indication include patients with symptoms of angina and/or evidence of myocardial ischaemia, and more extensive coronary artery disease, who have relative contra-indications to coronary surgery. In these cases, it is important to discuss the options with the patient with regard to the features of their individual case and in the light of local experience and results.

Surgical revascularisation – indications and trials

Coronary artery bypass grafting (CABG) is one of the most common operations performed today despite its recent beginnings. Cardiac revascularisation is undertaken either to minimise symptoms or to prevent premature death. CABG constitutes one of the three main categories of angina management, the other two being medical management or PCI.

A number of trials have now been conducted over the last three decades comparing these three management options resulting in the development of indications for surgery, PTCA or medical management for patients with chronic stable angina.

Three randomised controlled trials conducted in the 1970s6–8 demonstrated that CABG had a survival benefit when compared to medical management for patients with significant (> 50%) left main stem stenosis, triple vessel disease or two vessel disease with left ventricular dysfunction.

No study has shown any survival benefits for CABG over medical management for patients with single or two vessel disease. Revascularisation in this
group of patients is usually undertaken for symptom control when maximum medical management has been unsuccessful in improving their symptoms. PTCA or CABG are the two means of revascularisation available to this group of patients. Trials comparing CABG and PTCA for these patients show similar quality of life indices, stress test performance and clinical improvement. However, patients on whom PTCA was undertaken more often needed further revascularisation in the future due to re-stenosis. Growing interest in stents has led to their use for sub-optimal PTCA, chronically occluded arteries and re-stenosis after PTCA along with other indications.

It is important that secondary preventive measures are also used. Aspirin should be used to lower the rate of graft occlusion following CABG (21% versus 30%). Lipid lowering drugs should also be commenced.

CABG may not be advisable on the elderly population or on high-risk patients due to their co-morbidity. There are scoring systems such as the Parsonnet or Euroscore which give an estimate of the risk of in-hospital death after CABG. These risks of intervention compared with non-intervention should be explained to the patient, especially when obtaining consent.

Transmyocardial revascularisation

Patients unsuitable for revascularisation on whom medical management has been inadequate to control their symptoms can undergo transmyocardial revascularisation (TMR). TMR is a surgical procedure performed via a lateral thoracotomy. The surgeon places the laser on the epicardial surface of the left ventricle and discharges sufficient energy to create transmural channels in the myocardium. Percutaneous myocardial revascularisation (PMR) is performed via a cardiac catheter. Laser energy is applied to the endocardial surface of the heart to create partial thickness channels.

The precise mechanism of action of TMR is yet to be characterised. Randomised controlled trials of TMR versus medical management report improvements in the patient’s symptoms. These are sustained at 3 years in some reports making placebo as an explanation less likely.

PMR offers similar clinical benefits but with a better safety profile. It avoids a general anaesthetic and thoracotomy. The endocardial laser allows access to a greater surface area of the myocardium than TMR, which is largely limited to the anterior and lateral walls. Results from on-going trials are awaited.

Surgical conduit

Saphenous vein has been the mainstay for CABG. However, there is now a shift to arterial revascularisation owing to the longer patency rates seen with arterial conduits. The saphenous vein is usually in plentiful supply.
and easy to harvest and is, therefore, very much still in use. However, due to thrombosis, fibro-intimal hyperplasia or continued atherosclerosis, only 50% of these grafts remain patent at 10 years. Interestingly, of the grafts that have not occluded at 5 years, 80% remain patent at 10 years.

The left internal thoracic artery (LITA) has superior patency rate when compared to the saphenous vein graft of 83–93% at 10 years. Remarkably, this artery is very often spared of any atherosclerotic changes allowing it to be used routinely as the first conduit of choice. It is usually used to graft the left anterior descending artery (LAD) which supplies a large territory of the heart. These facts have now made the LITA to the LAD one of the most commonly performed procedures. However the following conditions may preclude its use: brachiocephalic and subclavian disease, very poor left ventricular function, previous irradiation, or in an emergency where the saphenous vein is better as faster restoration of blood flow is required.

The right internal thoracic artery (RITA) can be used to graft the right coronary artery or the posterior descending artery. It is generally better not to cross the RITA to the left system as this can make subsequent sternotomy treacherous. The use of bilateral ITA is associated with less angina, fewer myocardial infarctions and a reduced need for re-operation. However, it shows no further survival benefits and is also associated with a greater incidence of sternal wound infection. Therefore, its use is generally avoided in patients prone to infection such as diabetics and the obese.

The radial artery is now being used more commonly as the second arterial conduit of choice. After initial disappointing results, its patency rate has improved (93% at 1 year) with the use of prophylactic calcium channel blockade to prevent spasm.

The gastro-epiploic artery constitutes the third arterial conduit for an initial operation. The vessel is harvested from the greater curvature of the stomach from where it runs either in front of or behind the pylorus and the left lobe of the liver and through the diaphragm. Alternatively, it can be taken as a free graft. The pedicled graft has a patency of 92% at 5 years as compared to 88% seen with the free graft. The artery can reach all the three main vessels of the heart but is usually used to graft the inferior and lateral portions of the heart.

The inferior epigastric artery, short saphenous vein and cephalic vein have all also been used as conduits. There is, however, no large follow-up to study long-term results. Artificial conduits have as yet proved unsuccessful, achieving rates of less than 40% at 1 year.

**Future developments in surgical revascularisation**

Recently, there has been increasing interest in off-pump procedures. In such operations, a sternotomy is required but the operation is performed...
on the beating heart. Thus cardiopulmonary bypass is avoided along with all its associated inflammatory reaction. The concern, however, about the quality of the anastomosis achieved as it is performed on the beating heart. Nevertheless, there are reports of results comparable to conventional CABG as assessed by follow-up angiography. Improvement in stabiliser technology has resulted in some reports of people achieving total revascularisation off-pump. However, for more diffuse disease requiring multiple grafts, off-pump surgery is usually unsuitable.

Off-pump operations can be provided via a small anterior thoracotomy, thus avoiding a sternotomy. This minimally invasive, direct coronary artery bypass (MIDCAB) is also being developed with endoscopic and computer assisted techniques. Limited case series have been reported. These show good graft patency, smaller wound size and reduced hospital stay.

How future studies develop indications for such procedures is awaited with interest. One will need to see how these procedures either replace the current conventional means of revascularisation or establish their own niche.

Key points for clinical practice

- Left heart catheterisation (selective coronary arteriography and left ventriculography) helps to define prognosis, and the patient’s technical suitability for revascularisation
- Referral for left heart catheterisation is a key step to identify patients needing revascularisation
- Coronary artery surgery effectively relieves angina in all categories of patient, and improves prognosis in those with extensive coronary disease
- Percutaneous coronary intervention (angioplasty) is used in patients with angina who have less extensive disease or who are unsuitable for coronary surgery because of pulmonary, renal, or cerebrovascular disease
- Developments in stenting and in adjuvant drug treatment have improved the results of PCI, and have extended the indications.

References

3 Gruntzig AR, Senning A, Siegenthaler WE. Nonoperative dilatation of coronary artery stenosis:
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