Coronary Arteriography: The Diagnosis of Coronary Artery Disease

J. D. DOW, MC, MD, FRCP Ed, Radiologist, Guy's Hospital, London

By the end of 1973, 485 selective coronary arteriograms had been performed at Guy's Hospital, 139 by the method of Sones (Sones and Shirey, 1962) and 346 by that of Judkins (1967) with a successful cannulation and injection rate of over 95 per cent. The causes of failure in any individual case have usually been either severe coronary ostial stenosis or, more frequently, because the patient has been in border-line left heart failure and has gone into pulmonary oedema during the examination, which has then had to be abandoned.

Examination of the coronary arteries is preceded by a left ventricular angiocardiogram and it has become customary to use the right anterior oblique position. If, during the examination, there is a suspicion of a clot in the left ventricle a further similar examination is undertaken in the left anterior oblique position. It is essential to include a left ventricular angiocardiogram because the degree of contractility of the myocardium is one of the main surgical factors in assessing the patient's suitability for operation (Bigelow, 1971). In interpreting the angiocardiogram considerable attention is paid to the ventricular ejection fraction which should not be less than 40 per cent for successful surgery (Collins et al., 1972). Estimation of the ejection fraction is frequently made more difficult by ventricular extrasystoles and these can be minimised, if not entirely prevented, by using a slow injection time of about 10 ml/second.

Initially each coronary artery was injected in different positions five or six times. However, it was found that this relatively large number of injections increased both the morbidity and the mortality of the procedure. Injections are now restricted, usually to two in the right coronary artery, one in the 10 to 15 degrees left anterior oblique position and one in the 30 degree right anterior oblique position; and three in the left coronary artery, two in the right anterior oblique at 40 and 60 degrees and one in the left anterior oblique position at about 60 degrees.

Table 1 illustrates the classification of arteriosclerotic arterial disease and the grading of ventricular disease used. In grade 3 left ventricular disease the presence of deep circular muscle contractions is important, as grafting may
Table 1. Classification of arterial and left ventricular disease

| Grade | Arterial disease                          | Left ventricular disease                  |
|-------|-------------------------------------------|-------------------------------------------|
| 0     | Normal                                    | Normal                                    |
| 1     | Insignificant plaques or stenoses         | Poor or absent localised contraction      |
| 2     | Significant single or multiple stenoses   | Ventricular aneurysm                      |
| 3     | Segmental total occlusion                 | Dilated ventricle with small ejection frac- |
|       |                                           | tion, generalised poor contraction        |
|       |                                           | (a) with deep circular muscle contraction;|
|       |                                           | (b) without deep circular muscle contraction|

improve the patient's condition. If there is no such contraction, grafting is seldom of value.

Very little need be said about the accuracy of coronary arteriography in demonstrating arteriosclerosis. It is as accurate as is arteriography in arteriosclerotic disease in any other part of the body. It will show clearly arteriosclerosis involving the major and medium-sized arteries down to vessels of about 100 to 150 μm in diameter. To achieve this degree of accuracy, however, it is necessary to use an enlargement technique which is now routine in most centres. Arteriography will not demonstrate disease in vessels that are less than 150 μm in diameter. Another important point that should be mentioned is that when there is an occlusion in an artery and the distal artery is filled by anastomotic vessels, the size of this distal artery as shown by arteriography is frequently less than the actual size of the artery as found at operation. This is directly analogous to the size of the popliteal artery when there is a block in the superficial femoral. It is important, because the distal artery is often the optimum site of insertion for a graft and, if other circumstances are favourable, no patient should be excluded from operation on the size of the distal artery alone.

Table 2 shows the mortality in this series of 485 selective coronary arteriograms. There were eight deaths. Four patients died of irreversible ventricular fibrillation despite immediate defibrillation and other appropriate resuscitative measures. Two patients developed hypotension and bradycardia and died despite prolonged external cardiac massage. In one patient the left Judkin's catheter dissected the main left coronary artery; this was proven at autopsy. One patient developed a fatal infarct four hours after an uneventful procedure. This mortality is higher than has been described elsewhere. Figures
Table 2. Causes of death (coronary arteriography)

| Causes of Death                                      | Case 1          | Case 2          | Case 3          | Case 4          |
|-----------------------------------------------------|-----------------|-----------------|-----------------|-----------------|
| Ventricular fibrillation                            | Catheter in arch of aorta | Test injection LCA | 1 LCA injection | 4 LCA injections |
| Hypotension, bradycardia, death                     | Case 5          |                  | Case 6          | Case 7          |
| Dissection LCA (Judkins)                            |                  |                  |                 |                 |
| Infarct 4 hours after uneventful examination        | Case 8          |                  |                 |                 |

485 examinations—8 deaths = 1.6%

such as 0.09 per cent (Sones, 1967) and two in 4,500 patients (Judkins) have been quoted but these figures come from extremely large centres specialising in this investigation, often examining patients who are capable of travelling long distances, whose disease may not be so severe as that of patients seen in smaller centres. Perhaps the data gathered in six different hospitals in San Francisco (Selzer et al., 1971) provide a more accurate idea of the risk. The mortality at the six hospitals varied between 0.05 per cent and 8 per cent with an overall mortality of 1 per cent in 2,025 patients. Four of the deaths in the series at Guy's occurred in the early cases investigated by the Judkins' technique.

It is quite obvious that coronary arteriography is a potentially dangerous procedure. As well as experience in dealing with emergencies as they arise there are two other measures that may assist in reducing the mortality. The first is to keep the blood pressure and the pulse rate up by giving 0.1 mg of atropine in any case in which the pulse rate is less than 70 or the systolic blood pressure less than 100. Since adopting this as a routine measure about two years ago no deaths from hypotension and bradycardia have occurred. The second is to perform only the radiological investigation at the time of the examination and not to combine it with other procedures such as right heart catheterisation.

The morbidity associated with selective coronary arteriography is summarised in Table 3 and essentially comprises ventricular fibrillation and asystolic arrest, the incidence of which has become much less since the routine use of atropine. Most cases of ventricular fibrillation respond immediately to defibrillation.

The percentage of cases suitable for operation depends, of course, on the strictness of the criteria employed before contemplating surgery. If the suit-
ability of the artery were the only factor in question, the number of patients capable of receiving grafts would be over 90 per cent because, in the majority of cases, arteriosclerosis affects the proximal major vessels and leaves the distal vessels suitable for grafting (Green et al., 1970). However, other factors must be taken into account and are summarised in Table 4.

Table 4. Factors in the selection of cases for operation

| Factor in the selection of cases for operation | Reference          |
|-----------------------------------------------|--------------------|
| 1. Contractility of left ventricle             | (Bigelow, 1971)    |
| 2. Size of coronary artery receiving graft     | (L’Esperance et al., 1972) |
| 3. Area of myocardial perfusion                |                     |
| 4. Site of implantation of graft               |                     |
| 5. Absence of distal disease                   |                     |

Bigelow (1971) has emphasised the importance of accurate assessment of left ventricular function, stressing that, unless there is good myocardial contraction, grafting is unlikely to be successful because fibrous tissue cannot be revascularised; and L’Esperance and his colleagues (1972) have re-emphasised the experience gained in femoro-popliteal by-pass surgery. They stressed three points—

1. The artery receiving the graft must be of reasonable calibre: in the case of a coronary artery at least 1.5 millimetres in diameter. This can easily be assessed at coronary arteriography, no matter what enlargement technique is used, by comparing the width of the artery in question with the known width of the catheter. At the same time, in estimating the arterial size, it should be remembered that the diameter of the artery distal to an occlusion may be found to be larger at operation than it appears to be in the arteriogram.

2. There must be a considerable area of myocardium supplied by the vessel and the area of myocardium must be well perfused. For example, a graft inserted in the main anterior descending artery should have a better chance of success than a graft inserted into its diagonal branch because, although this may be the same size as the main artery, the area of myocardium it is per-
fusing is smaller. As a corollary, it follows that a graft inserted proximally in a main vessel will have a better chance of remaining patent than a graft inserted distally in the same vessel.

3. A graft is not likely to be successful if there is any severe stenosis or occlusion distal to its point of insertion.

It is difficult to be absolutely certain, but taking all these criteria into consideration the percentage of patients who might be considered suitable for operation in this series—from a surgical point of view alone—would be about 50 per cent.

In Guy’s Hospital up to the end of 1973, 122 graft operations had been performed (Table 5). A total of 215 grafts were inserted, 93 into the right coronary artery, 90 into the anterior descending and 28 into the circumflex branches of the left coronary artery. In addition, the left internal mammary artery was anastomosed to the anterior descending in three cases and to the circumflex in one. In this series there were nine deaths, giving a mortality rate of 7 per cent. This is higher than in many of the series in America in which the mortality is usually less than 6 per cent (Gott, 1974) but, of course, mortality figures depend among other factors on whether the angina is stable or unstable (Sheldon et al., 1972), on the number of grafts inserted (Mitchell et al., 1970), and on the extent of arterial disease and impairment of left ventricular function (Effler et al., 1970). Of these nine deaths six occurred in patients who had Grade 3 ventricular disease and extensive three-vessel arterial disease.

Of the 122 surgical patients, 46 have been re-studied about six months after operation using clinical assessment, resting and exercise electrocardiography, bicycle ergometer studies, atrial pacing, selective coronary arteriography and left ventricular angiocardiography. Only the clinical and radiological findings will be considered here.

Table 6 summarises the results of this re-study in relation to the patency of grafts. Seventy per cent were patent grafts. Of the 25 occluded grafts it was possible to inject the stump in 15 and prove the occlusion; in 10 cases the graft could not be entered and was not demonstrated by a free aortic injection. It
Table 6. Patients re-studied 6 months after operation

|            |            |            |
|------------|------------|------------|
| 13 patients| 1 graft    | 11 patent  |
|            |            | 2 occluded |
| 30 patients| 2 grafts   | 42 patent  |
|            |            | 18 occluded|
| 3 patients | 3 grafts   | 4 patent   |
|            |            | 5 occluded |
| Total 46 patients | 82 grafts | 57 patent (70%) |
|            |            | 25 occluded|

is difficult to know whether these grafts were patent or occluded but it seems fairly safe to say that either they were occluded or that there was very little flow through them. The patency rate of 70 per cent 6 months postoperatively correlates well with the 65 to 75 per cent patency rate 4 to 12 months postoperatively reported elsewhere (Walker et al., 1972; Grondin et al., 1972). So far as the late patency rate is concerned, one of the best studies comes from the Montreal Heart Clinic (Grondin et al., 1973). Employing radiological evaluation of graft patency they quote a patency rate of 68 per cent one year postoperatively and 63 per cent three years postoperatively. A reduction in patency of only 5 per cent after two years is very encouraging.

The causes of graft occlusion have been well described by Jones et al. (1972) and they can be divided simply into two groups: (a) early occlusion, which is mainly surgical and technical in origin and which is associated with a flow rate through the graft of less than 50 ml per minute as measured at the end of operation; and (b) late occlusion, due first to medial fibrosis and endothelial proliferation which may reduce the lumen of the graft by as much as 90 per cent, and secondly, to progressive stenosis at the point of insertion of the graft.

The relationship of angina and operation is shown in Table 7. It was possible to review 41 patients 6 to 36 months after operation. This group was divided into those in whom the grafts were patent and in whom myocardial perfusion was better postoperatively than pre-operatively (29 patients) and those in whom the grafts were occluded and in whom myocardial perfusion was undeniably worse (9 patients). Of the 29 in whom perfusion was better the great majority were very much improved; in 23 the angina was either completely relieved or markedly diminished, in four there was little change and in two the angina was worse. These last six were mainly patients in whom, although the grafts were patent, myocardial perfusion through them was not
Table 7. Relationship of angina and operation

| 46 patients re-studied at approx. 6 months postoperatively |
|----------------------------------------------------------|
| Re-evaluated between approx. 6 months and 3 years postoperatively |
| 3 died |
| 2 lost to follow-up |
| 41 patients surviving between approx. 6 months and 3 years |
| 30 perfusion better |
| 23 angina relieved or improved |
| 5 angina same |
| 2 angina worse |
| 11 perfusion worse |
| 7 angina relieved or improved |
| 2 angina same |
| 2 angina worse |

particularly good. The surprising thing, however, is that in the nine patients in whom myocardial perfusion was undeniably worse six were almost completely free of angina while three were either the same or worse. It would appear therefore that relief of angina after this operation may be obtained in either of two ways: first, the way intended, by revascularisation of the myocardium, and secondly by the surgical creation of an infarct. This has, of course, been noted before in the literature (Jones *et al.*, 1972). In both these groups ventricular function was seldom improved postoperatively.

The most usual general medical indication for recommending aorto-coronary bypass grafting is intractable angina pectoris which a full course of medical treatment has failed to relieve. If these patients fulfil the surgical criteria previously described the mortality rate should be less than 6 per cent, and immediately postoperatively 85 per cent should have relief of angina while 60 per cent should experience no further chest pain (Gott, 1974). Thereafter the outlook for these patients largely depends on late graft patency, which has already been discussed.

The second, more debatable, indication concerns patients with unstable angina (the pre-infarction state) and any decision to operate on these patients must depend on the clinician’s individual understanding of the natural history of angina pectoris, in which a highly variable annual mortality rate ranging between 2-5 per cent and 9 per cent has been reported (Reeves *et al.*, 1974). Many general factors such as associated hypertension and left heart failure affect this mortality but so far as the extent of coronary arterial disease is concerned the annual mortality rate is said to vary between 2 per cent when one major artery is affected and 11 per cent when all three are diseased (Morberg *et al.*, 1972; Lichtlen and Moccetti, 1972). The operative mortality is higher in this group than in patients with stable angina (Conti *et al.*, 1973)
and any decision to recommend operation must obviously vary from case to case depending on circumstances.

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