Minimally invasive therapy and robotics

T J Spyt* and A C De Souza†

*Glenfield Hospital, University Hospitals of Leicester NHS Trust, Leicester, UK and †Royal Brompton Hospital, London, UK

Considerable progress in the surgical management of coronary artery disease over the last several years has undoubtedly been influenced by developments in the technology of extracorporeal circulation and refinements in myocardial protection during surgery. This was associated with improvements in surgical technique, the introduction of quality suturing material, recognition of the importance of the choice of conduit and more appropriate selection of patients for intervention.

The introduction of safe cardioplegic arrest enabled immobilisation of the heart for a period of time necessary for the construction of multiple bypasses. The majority of cardiac surgeons adopted this strategy as safe for the patient and comfortable for the operator.

However, effective bypass grafting can be performed without the use of cardiopulmonary bypass. A small group of surgeons continued to follow the pioneering work of Kolesow who, in 1964, bypassed the anterior descending artery on the beating heart. Between 1995 and 1997, considerable interest was raised by Benetti, who postulated that bypass grafting can be performed satisfactorily through a limited left thoracotomy and without cardiopulmonary bypass. Benetti named this intervention MIDCAB (minimally invasive direct coronary artery bypass).

In parallel with the emergence of new surgical approaches, a number of reports claimed non-physiological impact of extracorporeal circulation. It has now been documented that cardiopulmonary bypass reduces quantity and quality of blood flow to vital organs, micro-embolisation, impairment of immunological response leading to increased rate of infections, renal dysfunction and the most important of all, neurological complications. As early as 1991, Benetti published the first comparison of costs of surgery with and without cardiopulmonary bypass, claiming considerable savings in the latter. The trend of limiting trauma caused by the access of surgery has not been unique to cardiac surgery. There is a considerable belief that, in some patients, trauma of the traditional access may be greater than the actual benefit of the surgical procedure. In fact, cardiac surgeons were late to join the trend seen in many other surgical specialties.

There are many reasons why cardiac surgeons started to look for new ways of performing myocardial revascularisation. Frequently, failures of cardiac surgical intervention are not caused by inadequate technique or errors, but by complications related to extracorporeal circulation and...
myocardial reperfusion. Generalised inflammatory reaction and activation of complement results in increased permeability of blood vessels, leading to fluid overload producing pulmonary and renal impairment. The release of complement C3A and endothelin 1 leads to spasm of coronary arteries; cytokinins, TNF-α, IL-6 and IL-8 contribute to negative influence on myocardial contractility and lead to a reduction in vascular resistance in patients undergoing surgery with cardiopulmonary bypass. Macro- and micro-embolisation seen following open heart surgery frequently originates from oxygenators, filters and atherosclerotic arteries. It is now documented that surgery without cardiopulmonary bypass does not lead to complement activation and embolisation is incidental. Cardiopulmonary bypass and sternotomy leads to a significant blood loss, hence the need for blood transfusion and clotting factors. In operations without cardiopulmonary support and through a small access, this problem does not exist. Limited surgical access makes the operation more difficult for the surgeon but a smaller wound, as in the case of the left limited thoracotomy, avoids injury to the sternum, producing a better cosmetic result and more effective postoperative analgesia. The hospital stay and convalescence in patients undergoing bypass grafting through a small thoracotomy is reduced in comparison with patients subjected to median sternotomy. Not surprisingly, this procedure has generated considerable interest amongst patients and hospital managers.

Minimally invasive direct coronary artery bypass

Patients suitable for MIDCAB procedures are those with obstruction in the proximal left anterior descending artery (LAD). Patients who benefit the most are those with: (i) severe impairment of left ventricular function; (ii) important co-existing co-morbidities; (iii) failed bypass grafting to left anterior descending coronary artery with venous conduit; and (iv) restenosis following angioplasty. The anterior descending artery should be at least 2 mm diameter and it is essential that the course of the artery is superficial. Intramyocardial position of the LAD could put construction of the anastomosis at risk. It is essential that the artery is not calcified. In ideal circumstances, the anterior descending artery would be occluded with a good collateral filling. In some patients, it is possible to combine the left internal thoracic artery bypass to LAD with angioplasty to the circumflex and right coronary arteries (hybrid procedures). Measurable benefits of the operation are minimalisation of surgical trauma, reduction in hospital stay and cost of treatment, elimination of complications specific to cardiopulmonary bypass, and the ability to accept patients with particularly high risks. The cosmetic results are excellent.
Bypass grafting through limited access is performed on the beating heart without the support of cardiopulmonary bypass. It is desirable that the heart rate is reduced to 60 beats/min using pharmacological preparation with β-blockers and calcium channel blockers. The patient receives standard premedication. Either endotracheal intubation or laryngeal mask is used and thoracic epidural anaesthesia is essential. Left anterolateral thoracotomy is carried out through the fourth intercostal space. The length of the incision is usually 7–10 cm. Occasionally it is necessary to remove part of the fourth cartilage. The left internal thoracic artery is dissected using either direct visual control or thoracoscopy. It is necessary to detach the left internal thoracic artery from the chest wall to obtain a segment of artery approximately 10 cm long. The pericardium is opened next and the anterior descending artery identified. The artery needs to be occluded above and below the site of planned arteriotomy. Alternatively, an intravascular shunt may be used. A segment of the anterior left ventricular wall containing the anterior descending artery is immobilised using a commercially available instrument (Cardiothoracic System® or Medtronic Octopus® device). Heparin is administered in a dose of 1 mg/kg body weight. The anastomosis of the left internal thoracic artery to the anterior descending artery is carried out using a conventional technique of continuous either 7/0 or 8/0 Prolene. During the anastomosis, the ECG is closely monitored. It is desirable to monitor the function of the left ventricle using transoesophageal echocardiography. Once the anastomosis is completed, the chest wall is closed in layers over a single intercostal chest drain. Reversal of heparin is not necessary.

An alternative to the small left anterior thoracotomy is partial sternotomy. The sternum is incised from the xiphoid to the level of the third intercostal space where it is transected. The left internal thoracic artery is dissected and the rest of the operation is carried out as described above. The partial sternotomy does not disrupt the integrity of the sternum to the same extent as the standard approach. The advantage of performing the operation through a partial sternotomy is simplicity of dealing with potential complications which may require the institution of cardiopulmonary bypass. No new incision is required except extension of the existing one.

Operations using limited access are technically difficult. This is mainly because the majority of cardiac surgeons are used to larger access. Movement of the heart has been eliminated by recently developed instruments. Limited access creates concern that incomplete dissection of the internal thoracic artery may lead to a ‘steal syndrome’. This concern has led to the introduction of video-assisted thoracoscopic techniques for harvesting of the internal thoracic artery. An increasing number of surgeons are capable of performing procedures using endoscopic instruments. As this experience increases, it creates potential that in the future the vascular anastomosis itself could be carried out endoscopically.
Results of coronary artery bypass grafting through limited access are not different from those performed using classical approaches. Early patency rates are as high as 98–99%. Mortality of the procedure is less than 1% and only very few patients need to be converted to bypass grafting with the use of extracorporeal circulation\textsuperscript{16–18}. If the long-term results remain as good as early outcomes, the operation may become a useful choice, even for patients with multivessel disease. This is because, even now, it can be successfully complimented by angioplasty. A large multicentre trial is currently being carried out in Britain to compare the outcome of angioplasty and stenting to the anterior descending artery with bypass grafting through a limited anterior thoracotomy (Angioplasty versus Minimally Invasive Surgery trial – AMIST trial).

Off pump CABG (OPCAB)

Multivessel coronary artery disease can also be treated surgically without the use of extracorporeal circulation. Easy access to the coronary arteries, which are on the surface of the heart, and introduction of instrumentation enabling immobilisation of the left ventricle have made the procedures possible\textsuperscript{19}. However, complete modification of the anaesthetic and surgical techniques had to follow. It is desirable to perform the operation with the use of arterial conduits only, which avoids manipulation of the ascending aorta, frequently affected by atherosclerosis. The third bypass can be constructed using the radial artery which in its proximal part is anastomosed to the side of the left or right internal thoracic artery. The most severely affected coronary artery should be dealt with first. This strategy allows protection of the most vulnerable part of the myocardium. Bypasses to the remaining arteries are carried next. The most treacherous part of the procedure is the bypass grafting to the dominant right coronary artery. This is frequently associated with episodes of hypotension and arrhythmia varying from atrial fibrillation to a complete standstill. Insertion of intravascular stent may prevent these unwelcome occurrences. In practice, the anterior descending artery is bypassed first. This offers protection not only to the anterior wall of the left ventricle, but also to the intraventricular septum. Exposure of the heart is facilitated by placement of traction sutures at the back of the pericardium, mainly above the left upper pulmonary vein or between the left upper pulmonary vein and the diaphragm, or between the left upper pulmonary vein and the inferior vena cava. Manipulation of the heart and stabilisation of the part of the left ventricular wall may lead to sudden hypotension. Reduction of the preload caused by lifting the heart should be corrected by changing the position of the patient and by administration of intravenous fluids. Occasionally it
is necessary to administer catecholamines. Intra-operative tachycardia can be treated with an infusion of short acting β-blockers and profound bradycardia will require temporary pacing. Patients need careful monitoring which includes ECG, pulse oximetry and measurement of peripheral arterial and central venous pressures. Intra-operative transoesophageal echocardiography and Swan Ganz catheterisation are desirable. Heparin is given in a dose of 1 mg/kg body weight to achieve activated clotting time of 250–300 s. Maintenance of normothermia is essential and this is achieved by relatively high temperature in theatre (22°C or more), preheating of the patient during induction of anaesthesia, active warming during surgery using air blankets (Bear Hugger®) and also by administration of warmed intravenous fluids. Early results of the more complex revascularisation procedures off pump are good, although no large randomised trials exist to encourage further dissemination of the technique. Early psychoneurological assessments of the patients, however, indicate better outcomes amongst patients who underwent surgery without cardiopulmonary bypass.

Coronary artery bypass grafting through limited access with the use of extracorporeal circulation (port access CABG)

This method of coronary artery bypass grafting involves cardiopulmonary bypass and cardioplegic arrest. Surgical access is obtained through several smaller incisions; in some cases, a limited left anterior thoracotomy is performed. The patient is intubated with a double lumen tube. Arterial pressure is monitored in both radial arteries. Debrillator pads are attached to the chest. One or both internal thoracic arteries are dissected using video-assisted thoracoscopy. After heparinisation, the femoral artery and vein are cannulated in the groin. It is also possible to cannulate the ascending aorta through a separate incision in the first intercostal space. The venous cannula is advanced to the level of the ostium of the superior vena cava. The internal thoracic artery is divided distally and the pericardium is opened vertically through a mini-thoracotomy. Cardiopulmonary bypass is supported usually with a centrifugal pump. If venous conduits are used, the proximal anastomosis on the aorta is carried out using a small side-biting clamp. The ascending aorta is clamped and cardioplegia administered. The heart is decompressed through a separate cannula which also serves to occlude the aorta from inside by expanding a balloon (endoclamp) positioned above the aortic valve under echocardiographic control. The same cannula is also used for the delivery of cardioplegic solution once the ascending aorta has been occluded. Misplacement of endoclamp will be
noticed by a difference in arterial pressure monitored from both radial arteries. Observation of arterial pressure is important, as misplacement of the balloon may occlude branches of the aorta, thus jeopardising cerebral blood supply. Bypass grafting is performed once the heart is stopped. Some surgeons prefer mini-thoracotomy, others use multiple small incisions employing small ports for access for which specially designed instruments are essential. Once all distal anastomoses are completed, the endoclamp is deflated and removed. Cardiopulmonary bypass is discontinued and heparin reversed. The femoral vessels are decannulated and all incisions closed.

Port-access surgery is usually performed in selected patients with a low risk of peri-operative mortality, in centres with a large surgical experience. To date, published data describe no more than 2000 patients who have undergone this form of surgery. The time of cardiopulmonary bypass and ischaemic cardiac arrest is considerably longer and the operation takes 4–5 h. The number of patients requiring conversion to a standard sternotomy is minimal. Peri-operative mortality is also less than 1%. Neurological complications, however, are seen in approximately 2% of cases. The important complication of this approach is the possibility of dissection of the aorta observed in 1% of patients. This is considerably higher than during standard procedures. Re-exploration for bleeding is more frequent. Some patients develop healing problems in the groin. Hospital stay is short and early angiographic results of surgery indicate 97–100% graft patency. As this form of surgery has been carried out only since 1996, there are no published reports describing long-term outcome.

The idea of endoscopic cardiac surgery, supported by cardiopulmonary bypass, was initiated as early as 1991 in Stamford Surgical Technologies. This development was kept secret until 1995, when the company changed its name to Heartport Inc. An undoubted advantage of port-access is the ability to perform full revascularisation on the still heart through surgically small incisions, which gives an excellent cosmetic result. However, this is achieved by increased cardiopulmonary bypass and ischaemic time, and increased risk of serious vascular complications. The technique requires a long training, the operations take considerable time and the equipment is expensive. In comparison with the MIDCAB and OPCAB procedures, port-access is unlikely to become common place. In wealthy societies, where small incisions may be attractive to the patients for cosmetic reasons, port-access may be an alternative to the traditional approach as long as there are no major systemic risk factors, no peripheral vascular disease and the function of the left ventricle is good enough to withstand 2–5 h of extracorporeal circulation. To our knowledge, no British centre at present carries out a regular programme of port access coronary artery bypass grafting.
References

Ischaemic heart disease: therapeutic issues