Robotic coronary artery surgery

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Abstract

Cardiopulmonary bypass and the median sternotomy incision have revolutionised cardiac surgery, helping coronary artery bypass to become a routine procedure. Cardiopulmonary bypass was originally developed to allow open-heart surgery, but was adopted for coronary surgery because it provided a still operating field. However, the cost of good surgical access has been a large scar, with slow recovery and occasional serious wound complications.

Adaptation of robotic technology from production engineering provides a new way of performing coronary artery bypass grafting (CABG) without large incisions, and often without cardiopulmonary bypass. Although the first endoscopic robotic cases were reported several years ago, widespread adoption of the new technique is still some way off. We review the progress of robotic CABG to date, and discuss current research fields.

Key words: coronary artery surgery, robotic, minimally invasive, endoscopic.

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Introduction

Minimally invasive cardiac surgery stemmed from the desire to avoid the known complications of sternotomy. After sternotomy, patients show impaired respiratory mechanics as pain decreases deep inspiration and coughing, causing atelectasis and sputum retention. Sternotomy wounds involve extensive bone cutting (together with devascularisation if the internal thoracic arteries [ITAs] are harvested), risking post-operative bony non-union or osteomyelitis, which carry significant morbidity. Wound complications are more common in diabetic, obese and elderly patients, who form an increasing proportion of surgical patients. The overall incidence of sternotomy wound infection is 2–3%,[1] with a mortality rate for isolated CABG in the UK of 2%.[2] Following uncomplicated sternotomy, bony union takes up to three months, limiting the patient's activity and return to work.

Unlike some other surgical procedures, CABG faces direct comparison with percutaneous stent treatment, which is far less invasive, has a shorter convalescence period and is less expensive on a per-procedure basis.[3,4] However, large randomised controlled trials have demonstrated higher reintervention rates for both single vessel left anterior descending (LAD) and multiple vessel disease when treated by stenting compared to surgery.[3-6] In addition, tortuous or obstructing coronary lesions are often unsuitable for stenting, necessitating surgery. Nevertheless, stent technology is continuously improving. As outcomes following stenting have improved, surgeons have responded by attempting to decrease the morbidity of CABG.

Stepping stones to endoscopic CABG

Endoscopic CABG has been made possible by a number of progressively less invasive techniques developed over several years.

The MIDCAB (Minimally Invasive Coronary Artery Bypass) procedure was popularised in the 1990s.[7,8] It involves an anterior left minithoracotomy to provide access for harvesting of the left ITA and beating heart ('off-pump') anastomoses to coronary arteries on the anterior surface of the heart – the LAD and diagonal arteries. Left lateral and right-sided incisions have been described for proximal circumflex and right coronary grafting, respectively.[9] However, the incision does not provide sufficient access for multiple vessel (i.e. both left- and right-sided) or posterior vessel grafting.

Meta-analysis of MIDCAB trials with and without stabilisation devices has shown improved stenosis and occlusion rates with the use of stabilisation,[10] presumably due to technically superior anastomoses. Stabilisation devices produce almost complete immobilisation of the anastomotic site, allowing fine suturing. Angiographic patency data achieved with MIDCAB and stabilisation are similar to conventional surgery data.[11-13] Another difficulty of this approach has been identification of the LAD, and some surgeons have reported accidental grafting of diagonal vessels instead of the LAD.[12]

MIDCAB surgery does, however, involve thoracotomy and forceful rib retraction and is no less painful than sternotomy.[14] This, and difficulty with mobilising the proximal ITA, led to the use of thoracoscopic techniques to harvest the ITA.[15] Thoracoscopic dissection allows a very small mediastinotomy

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Figure 1. Zeus system in position to begin totally endoscopic CABG

Figure 2. Control console during mammary artery mobilisation

Figure 3. Cosmetic appearance six weeks following totally endoscopic CABG

incision for coronary anastomosis, and is less painful post-operatively.[16] Angiographic results in a series of 46 endoscopic ITA harvest patients showed a patency of 97.8%.[17] Endoscopic ITA dissection followed by a very small (5–6 cm) thoracotomy for anastomosis is known as the endo A-CAB procedure (endoscopic atraumatic coronary artery bypass).

This experience has shown that endoscopic ITA harvest is a safe procedure, and that acceptable patency results can be gained with limited surgical access provided the operating site is immobilised. The difficulty of operations on posterior coronary arteries without a sternotomy and cardiopulmonary bypass has also been established. With experience from MIDCAB and endoscopic ITA harvest surgery, several surgeons felt ready to grasp the opportunity of totally robotic CABG when the technology developed in the late 1990s.

Robotic technology

Two surgical robotic systems are currently commercially available, the Computer Motion Zeus® system (figure 1) and the Intuitive Surgical Da Vinci® system. Both involve a distant console where the operator controls joystick controls (figure 2). A computer processor then reduces the scale of the surgeon's hand movements (removing natural hand tremor) and translates them into movement of the robotic thoracoscopic instruments in the chest. These systems allow surgical procedures to be performed on the heart without an open chest incision. The instruments are laparoscopic, with 'wrist' joints on the operating end to allow rotation of the operating tips. Stereoscopic 3D camera and headset systems provide excellent visualisation, although as yet the operator has no tactile feedback during a robotic operation. Camera images and control signals can be sent electronically, allowing a surgeon to be assisted and mentored by a colleague who may even be on another continent. Indeed, 'international surgery', with operator and patient in different countries, has already taken place.[18]

Thoracoscopic surgery requires single lung ventilation to provide enough space within the chest, and this is usually augmented by carbon dioxide insufflation.

To allow minimally invasive valve procedures and on-pump CABG several methods of providing cardiopulmonary bypass have been used. These include the Heart Port system, in which femoral arterial and venous access is used to pass arterial and venous catheters into the right atrium and ascending aorta. These and similar systems have been used to perform on-pump endoscopic CABG, particularly in early series, although as a long-term goal most surgeons would prefer to avoid groin scars (following femoral cannulation) and the morbidity of cardiopulmonary bypass.[19]

Table 1. Numbers of patients, numbers of grafts, conversion rates and patency data in three robotic coronary artery bypass series

Author	No. of patients	On or off pump	No. of grafts	Operating time (hours)	Conversion rate to sternotomy or MIDCAB	Patency data (percentage, method and time from surgery)
Mohr 2001[25]	27	On	One (all LAD)	3.5–8	18.5%	95.4% (angio at three months)
	8	Off	One (all LAD)	No data	75%	No data
Dogan 2002[24]	37	On	One	4.2 ± 0.4	19%	100% (only first 22 cases studied = 49%)
	8	On	Two	6.3 ± 1.0	50%	As above
Kappert 2001[26]	8	On	One	1.7–8.0	36%	No data
	29	Off	One	As above	As above	No data

Key: LAD = left anterior descending; MIDCAB = minimally invasive coronary artery bypass

N.B. Operative times and conversion rate in Kappert on- and off-pump groups were reported together.

Robotic coronary artery bypass

Animal studies suggest that robotic anastomoses have similar levels of microscopic tissue trauma and angiographic patency as freehand anastomoses.[20,21] After a stepwise training programme, two groups reported the first totally endoscopic coronary artery bypass grafts (TECAB) performed in humans in 1999.[22,23] Both groups reported two patients, using cardiopulmonary bypass and cardioplegic arrest: one group used the Zeus system,[22] the other the Da Vinci system.[23] Since then several groups, including our own, have performed similar procedures (figure 3),[24-26] usually involving anterior single vessel grafting, although multiple anterior vessel surgery has been reported.[24] The operative times, conversion rates and post-operative patency data are shown in table 1.

All series have shown both long operating times and high conversion rates, particularly to the MIDCAB approach. These series all include early 'learning curve' cases, where operators may be expected to be slower and to convert to open surgery earlier than they might do after further experience. Pleural and pericardial adhesions, and difficulties with stabilisation or performing the anastomosis have been cited as reasons for conversion to sternotomy or MIDCAB.

Robotic cases are more expensive than both MIDCAB and sternotomy CABG.[27] As yet, a method for grafting posterior and inferior coronary arteries has not been developed.

Patients who require post-operative exploration for bleeding have mostly undergone sternotomy, although our group and others have limited experience of successful thoracoscopic re-exploration.[26]

Bilateral mammary harvest can be performed using instruments inserted via only one side of the chest.[24]

Current developments

To cut down anastomosis times, several manufacturers are developing anastomotic assist devices to connect coronary arteries to grafts: they draw on several technologies, including stenting and magnetic attachment.[28,29] Most are designed to be easier to deploy by robot than suturing, and the first devices are now available. These devices are extremely promising, but leaving prosthetic material within the lumen raises the possibility of neointimal hyperplasia, as has been seen in stenting. Long-term patency data will need to show equivalence to sutured anastomosis results before such devices are widely used.

Another option is to use robotics to provide an ITA–LAD graft, and to treat other vessels percutaneously. This 'hybrid' approach has already been investigated with MIDCAB surgery,[30] and more recently with robotic endo A-CAB surgery.[31] The early results of drug-eluting stents have added to interest in the hybrid approach.[32] Observational clinical trials of hybrid revascularisation show one year reintervention rates of 11.4–12.7%,[33-35] compared with 16.8% revascularisation at one year for the multiple vessel stenting arm of the Arterial Revascularisation Therapy Study (ARTS).[4] The majority of reintervention in these hybrid series was attributable to in-stent stenosis. Patients with disease that is not amenable to stenting are not suitable for hybrid revascularisation, and will require conventional surgery. The reintervention rate for this procedure compared to conventional surgery has yet to be tested in randomised trials.

Key messages

- In isolated left anterior descending disease minimally invasive surgery (rather than stenting) has improved reintervention-free survival
- MIDCAB, endo A-CAB or robotic (TECAB) procedures are all able to treat single vessel anterior coronary artery disease
- Totally endoscopic CABG (TECAB) currently has a high conversion rate to MIDCAB, and long operating times
- Initial angiographic follow-up of robotic anastomoses suggests patency > 95%
- Totally endoscopic multiple vessel grafting has not been achieved in large series
- Current research is focusing on anastomotic devices to reduce endoscopic anastomosis times; and hybrid revascularisation, which combines robotics with stent procedures

Conclusion

Robotic surgery is possible in single LAD and some double vessel disease. As yet, advantages in terms of decreased morbidity, decreased hospital stay or improved recovery sufficient to offset the increased time and expense required have not been conclusively demonstrated. The chief problems have been the time required to perform a sutured anastomosis, the difficulty of performing multiple grafts and the high conversion rate in current series. Conduit-coronary anastomotic devices will decrease operating times, but will need to show long-term patency equivalent to sutured anastomoses. Hybrid procedures, particularly with drug-eluting stent technology, may provide a solution to the problems of posterior vessel grafting whilst providing the benefit of pedicled ITA–LAD grafting. Minimally invasive coronary surgery is certain to continue to expand, driven by technological development and patient demand.

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