Expanding Surgical Options Using Minimally Invasive Techniques for Cardio-aortic and Aortic Procedures

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In an effort to minimize the morbidity and mortality of open cardio-aortic and aortic operations, which are ranked among the most extensive procedures, surgeons are attempting to use smaller minimal-access incisions, less-invasive open procedures, or more distal access sites to place aortic stented grafts by intraluminal closed methods. We review the latest trends in this rapidly evolving new field of minimally invasive surgery. Arch Surg. 1998;133:1160-1165

Traditionally, the consensus in surgery has been that the larger the incision, the better the exposure, and the better the operation performed. Indeed, a frequently quoted adage is that the incision “heals from side-to-side, not end-to-end.” These views are now being challenged by new surgical innovations in the form of minimally invasive operations and percutaneous or peripheral approaches to cardio-aortic or aortic problems. The minimally invasive techniques are more demanding of the surgeon and more difficult to teach, but should benefit the patients because less trauma is caused, less postoperative pain results, and the operations are safer, resulting in reduced costs. There are several issues that need to be addressed as this field evolves, such as mortality rates, complication rates, patient satisfaction, long-term durability, and the cost of these minimally invasive approaches.

CARDIO-AORTIC AND THORACIC AORTIC PROCEDURES

Open Procedures

The problem with any procedure involving the heart valves and the ascending aorta or the aortic arch is that cardiorespiratory function has to be supported during surgery. In the case of aortic arch repairs, the brain must also be protected. Thus, the minimally invasive open procedures still require the use of cardiopulmonary bypass. In an attempt to make operations less invasive to the patient, Navia and Cosgrove1 pioneered the technique of using a right parasternal incision with division of a second and third (occasionally a fourth) rib to approach the mitral or aortic valves. Cardiopulmonary bypass was established by cannulating the femoral artery and vein. They also described using a transverse sternotomy in the second interspace for aortic valve replacements, which also necessitated division of the 2 mammary arteries.2 In a series of 115 patients undergoing minimally invasive valve operations, Cosgrove et al3 reported that patients were discharged earlier and hospital costs were reduced. There was only 1 death, a patient who had a stroke. Cohn et al4 also used this parasternal method for mitral valve operations and achieved similar results. Another approach to cardiac valves is videooscopic surgery. With the newer 3-dimensional imaging, the remote control of instruments has become considerably easier because sufficient depth of field is perceived. Nonetheless, the reversal of movement internally as opposed to the movements at the surgeon’s fingers continues to be a problem. In this evolving field, robotic remote control is being investigated to overcome some of these technical difficulties, the advantage being that with specialized hand controls, the robot moves the instrument in the direction or rotation that would be expected as opposed to the opposite direction, as with videooscopic surgery. Furthermore, the robot-held intru-

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ments can be synchronized to move appropriately with the beating heart. This approach is still in its infancy and no published reports are available. Both the cost of this approach and the need for peripheral perfusion for open procedures will likely be limiting factors.

The parasternal approach and the transverse sternotomy approach do not give adequate exposure for more complex aortic procedures; therefore, we developed what we call a “J/j” incision sternotomy. For this minimally invasive approach, a 7- to 8-cm midline skin incision is made from the sternal angle to the level of the fourth intercostal space. For the aortic root and valve procedures, the sternum is cut with an oscillating saw from the right sternal margin to the midline at the first and fourth intercostal spaces, and then the sternum is cut in the midline, connecting the horizontal sternal incisions (Figure 1). This results in a sternal “J” incision through which the venous drainage and arterial infusion cannula can be inserted for cardiopulmonary bypass support and that gives good exposure for the ascending aorta or aortic valve. For more extensive procedures requiring distal ascending aorta or aortic arch exposure, the sternal incision is taken from the sternal notch down to the right fourth intercostal space, the “J” sternal incision (Figure 2). We previously reported using this incision for various types of operations, including aortic, cardioaortic, valvular procedures, atrioseptal defects, reoperations, and the Cox procedure for atrial fibrillation.

Prior to August 1997, we had done 37 minimally invasive valve and aortic operations using various approaches and wished to see if there was any benefit to the minimally invasive procedures. Pending any prospective randomized studies, we believed that it would be worthwhile to do a case-control study of these 37 patients. We observed that the postoperative length of stay was significantly shorter in those patients undergoing minimal-access operations, particularly in the subgroup of patients who had the “J/j” incision approaches—an average of 5.1 days vs 8.1 days in the control group (P < .001). Furthermore, the patients having a “J/j” incision required half as much postoperative morphine to control pain—20.6 mg vs 40.9 mg in the control group (P = .003). In this group of patients, there was one patient who died of adult respiratory distress syndrome in the postoperative period, although we did not consider this to be related to the operative approach because the patient was ventilator-dependent prior to surgery and had a history of pulmonary disease, including interstitial lung disease and chronic obstructive pulmonary disease. No patient suffered a stroke or clinically noted neurocognitive deficit in this group of patients. In the group of patients having “J/j” incisions, the average clamp time was 85.9 minutes with a cardiopulmonary bypass time of 113.5 minutes, which also included those patients undergoing complex aortic procedures with deep hypothermic circulatory arrest. In the patients who had aortic valve replacement alone, the average cross-clamp time was 44 minutes (range, 39-51 minutes). Of note, our preliminary findings show these minimal-access procedures do take longer to perform compared with a standard open procedure; although, with experience, we anticipate that the time will be reduced.

At the American Association for Thoracic Surgery postgraduate course, we presented our experience with minimally invasive aortic surgery up to March 31, 1998. We have performed 27 minimally invasive ascending aorta and aortic arch procedures. The aortic procedures included 9 composite valve grafts including the aortic arch.
in 4, 8 ascending aorta and aortic valve replacements or repairs, 6 ascending aorta plus aortic arch repairs, 2 ascending aorta and aortic root repairs with aortic valve preservation, 1 “elephant trunk” procedure with associated ascending aorta and aortic valve repair, and 1 combined entire thoracic aorta and thoracoabdominal repair down to the superior mesenteric artery. Eight were reoperations. One patient (3%) died after a composite valve graft insertion. This patient had been discharged 3 days after surgery and died on the 15th postoperative day with ventricular tachycardia. Autopsy failed to reveal any cause for this and the patient, on preoperative Holter examination, had been documented as having ventricular arrhythmias. These results compared with our total experience of ascending aorta and aortic arch surgery in 204 patients, with 4 deaths (98% survival) and 2 strokes (1%). A larger series of minimally invasive operations will be needed to determine if this is a safe approach, although in our experience now of more than 80 heart and aortic operations, we believe that this is a promising new approach in selected patients, particularly for reoperations.

The benefits seem to be that the postoperative pain is reduced and it is our impression that patients return to work earlier, particularly those who do manual labor. It is also our impression that respiratory problems are lessened after the minimally invasive procedures because the lower chest and diaphragm is not interfered with and, in the patients who have the "J" incision, the upper sternum is also intact. Because of both the reduced postoperative stay and the fact that we do not use any specialized equipment or technology, the cost of the operative procedures has been reduced. Learning the procedures is initially more difficult, particularly as visualization is not as good, but with experience the aortic cross-clamp and cardiopulmonary bypass times should become more acceptable.

### Closed Procedures

As yet, the ascending aorta and the aortic arch cannot be safely approached in patients via the femoral and iliac arteries and by placing catheter-guided stented grafts in the ascending aorta or the aortic arch. Nevertheless, research is being performed in animals to try and replace the aortic valve with catheter-based guidance systems from the femoral artery. The concern with any ascending aorta or aortic arch procedures being done via the femoral artery is the risk of embolization to the brain and stroke. Nonetheless, descending aortic abnormalities have been successfully treated with the use of stent grafts.

At the American Association for Thoracic Surgery meeting in May 1998, the Stanford University group presented their early experience with 109 patients, more than half of whom were not candidates for open repairs; 93% had complete thrombosis of the aneurysm, 92% survived, 4% had paraplegia, 3% had a stroke, 2% developed aortic dissection, and 1% had renal failure. On late follow-up, 16% had significant procedures or aorta-related events and 3% required an open repair. Stent grafts are now also being used for aortic dissection, including combination with proximal dissection aortic arch repairs and placing stented grafts aortoscopically into the descending aorta. We have also found it useful to reper-

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**ABDOMINAL AORTA**

In the infradiaphragmatic aorta and its visceral branches, 3 principal developments can be cited that are indicative of the application of minimally invasive technology. These are (1) adjunctive use of metallic stents to expand the application of renal artery angioplasty, (2) modifications of standard aortic reconstruction with either small incisions or endoscopic graft tunneling and/or laparoscopic instrumentation, and (3) endovascular stent-graft repair of abdominal aortic or iliac aneurysm. The latter is unquestionably the most significant of these, and likely the most important technical advance in the management of abdominal aortic aneurysm (AAA) since the first direct operative repair was reported by DuBois in 1951.

Conventional surgical repair of AAA produces excellent overall results. Even geographically based multi-institutional, multisurgeon studies document operative mortalities of 5% or less, with mortality rates half that figure typical of university-based series. Gravitational complications (ie, durability of repair) occur in fewer than 10% of patients, even with protracted follow-up. It is illogical to anticipate this sort of durability performance with endovascular repair, but the promise of diminished periprocedural morbidity and more rapid recovery is a valid consideration in many patients. Finally, cost considerations will eventually favor endovascular repair because of the greatly decreased need for in-hospital postoperative care.

Endovascular repair of AAA, first reported by Parodi et al in 1991, is here to stay. This procedure, wherein an "endograft" is deployed from within the AAA sac via catheter manipulation from a remote (usually transfemoral) access site, has been developed and applied at a "future shock" pace during the past 5 years. While this technology will remain in evolution during the next decade, and the long-term follow-up studies necessary to document its durability are as yet unavailable, the only re-
main issue is what percentage of AAAs will be treated with endovascular repair once its evolution is complete. Short-term feasibility, safety, and even efficacy are typically satisfactory in initial experience. Thereafter, patient selection considerations and device and protocol constraints become paramount. The European experience has evolved at an unbridled pace, whereas every potentially commercially available device in the United States has been introduced in the form of clinical trials sponsored by the US Food and Drug Administration, with the obvious advantage of rigorous data collection and the use of concurrent, if not randomized, controls. Patient selection criteria for endovascular repair are largely anatomy driven or a function of prohibitive operative risk for conventional repair. The percentage of AAAs treatable with endovascular repair will vary greatly in accordance with the patient’s candidacy for open operative repair. When rigid anatomical selection criteria are maintained, such as in protocol trials, that percentage will be in the 20% to 30% range. When high-risk patients (such that open repair is not feasible) are evaluated for endovascular repair, this percentage will climb to the 80% to 90% range and, in our experience, often requires the application of “homemade” devices; ie, those with modifications to minimize the anatomical constraints applied to protocol devices.

All AAA endografts have 3 basic components: a collapsible graft composed of polyester or polytet, an attachment mechanism to seal the graft-aortic (or graft–iliac) interface in watertight fashion, and a delivery system that positions and then permits deployment of the graft. The graft itself can be either totally stent-supported or have stent attachment devices at the proximal and distal ends. Most investigators believe that the totally supported construction is preferred to minimize graft kinking and obstruction at the iliac level. Similar to surgical reconstruction, the anatomical reconstruction can be aortic tube graft, aorto–bi-iliac graft, or aorto–uni-iliac graft complemented with femoral-femoral bypass to reconstruct circulation to the contralateral leg. While tube grafts are both preferred and feasible in most open surgical AAA repair, inadequate distal “neck” to seat an endoprosthesis above the aortic bifurcation is the rule, rather than the exception. Because tubular endografts are simple to deploy and were the first constructs available, sufficient experience has been accumulated to indicate that they are seldom feasible and that late dislodgment at the distal attachment site can occur. Thus, tubular constructs will be an unusual formation for endovascular repair of AAA in the future, but will be applicable in the thoracic aorta. Bifurcated endografts to the common iliac arteries are best constructed and deployed with a modular design concept. In this design, an aorto–uni-iliac graft is delivered on one side and the contralateral graft limb is delivered retrograde as a separate component into the main graft body. This modular design concept allows for simplicity of insertion and the flexibility to extend the graft at either the proximal aortic or distal iliac level. Aneurysmal common iliac arteries will generally prevent successful stent-graft attachment at the common iliac level.

This pattern of AAA anatomy can be grafted with an aorto–uni-iliac graft to the external iliac level with sacrifice of the ipsilateral hypogastric artery. Femoral-femoral bypass with retrograde common iliac occlusion and preservation of contralateral hypogastric flow completes the procedure. Virtually all endovascular repair are accomplished with large-bore introducer sheaths and require open femoral or retroperitoneal iliac arteriotomy access. Such complexities and the potential for technical mishap and conversion to open repair mandate that endovascular repairs be performed in a fully prepared operating room, usually under general anesthesia. Accurate intraoperative imaging for accurate graft deployment is typically accomplished with portable fluoroscopy units with road-mapping capabilities. Technical misadventure or failure to accomplish transfemoral access can lead to conversion to open repair. Such conversion rates range from 0% to 18%, but typically occur in fewer than 5% of cases and tend to cluster in the learning curve period. Careful case selection is the key to avoiding conversion.17–19

What are the anatomical constraints limiting endovascular repair? The first is an adequate AAA neck such that the proximal attachment device (analogous to the proximal anastomosis) will form a blood-tight seal between the endograft and the aortic wall. For most protocol devices, a minimum length of 1.5 cm and neck diameter of no more than 26 mm are required. In addition, excessive (>60°) neck angulation and/or the presence of mural atheroma can also interfere with tight seating of the proximal aspect of the stent-graft. Inadequate neck length can be overcome by modifying the stent-graft design to include proximal uncovered stent extensions, which can then be deployed directly in the visceral aortic segment. Patency of the renal and visceral vessel origins is maintained through the wide stent interstices, as the graft itself begins at the infrarenal level. Iliac artery stenosis, tortuosity, or aneurysmal disease can both limit or preclude device delivery and appropriate “sealing” of the iliac end(s) of the stent-graft.

Persistent flow into the AAA sac is referred to as “endoleak” and implies inadequate exclusion and the continued potential threat of AAA rupture. While endoleak can be detected at the time of graft implantation, it can occur years after apparently successful AAA exclusion if the endograft migrates from its attachment sites. The implications for mandatory radiological follow-up are obvious. Endoleak can occur at proximal or distal attachment sites, or can result from retrograde flow from the inferior mesenteric or lumbar arteries. The most serious situation is endoleak at the proximal attachment site, because these tend to be high flow, continue to pressurize the AAA sac, and generally require a proximal endograft extension (if adequate infrarenal neck length is available) or conversion to open repair. Alternatively, distal attachment and/or branch vessel endoleak will either undergo spontaneous thrombosis or be repairable with a second endovascular intervention in most cases. Endoleak is the principal cause of technical failure of endovascular repair and occurs in some 15% of cases.16–20 While it is entirely appropriate to report endoleak as a “primary” technical failure, most of these are corrected with sec-
secondary endovascular procedures and ultimately result in successful exclusion of the AAA.

Endovascular repair offers the promise of AAA treatment at reduced overall morbidity, cost, and more rapid recovery when compared with conventional surgical repair. In addition, endovascular repair can be offered to the 5% of AAA patients at prohibitive periprocedural risk for open repair. Our experience, which now exceeds 140 cases, has documented decreased cost, decreased length of stay, and more rapid recovery compared with open surgery. Similarly, conversion to open surgery is currently rare, and endoleak is a diminishing and a typically easily managed problem. May et al have provided a short metallic stent. To maintain patency of the renal artery ostium, the stent must protrude a few millimeters into the aortic lumen. Blum et al have reported the best results to date for RVD percutaneous transluminal angioplasty or stent. These investigators treated 74 renal artery lesions defined as ostial (within 5 mm of the aortic lumen) in 68 patients, including lesions with only 50% diameter stenoses. They reported 100% initial technical success, no major periprocedural complications, and a primary patency of 84% at a mean follow-up of 27 months. Endovascular reintervention resulted in a 92% secondary patency rate. While the reported results were superb in this study, certain characteristics of these patients (mean age 60 years, mean creatinine level 106 µmol/L [1.2 mg/dL], inclusion of 50% stenosing lesions) suggest that this patient cohort had a preponderance of low-risk cases. Rees et al reported updated results from a multicenter study of adjunctive stenting to rescue a “failed” renal percutaneous transluminal angioplasty. These investigators described angiographic restenosis, which typically occurs within the stent in a third of their patients. It seems clear that both technical success and complication rates with percutaneous transluminal angioplasty and stent for RVD will vary as a function of patient and lesion selection.

**MODIFICATIONS TO CONVENTIONAL SURGICAL RECONSTRUCTION**

In abdominal aortic surgery, the best analogy to the rapid development of minimally invasive techniques for cardiac surgery are the various attempts to achieve a conventional (open) surgical repair through smaller incisions. Several variations are in development, including: (1) an open approach through a small midline incision facilitated by specialized instrumentation and endoscopically assisted graft limb tunneling to the femoral artery; (2) laparoscopic-assisted surgery, where the bulk of dissection is performed laparoscopically and an open anastomosis is performed; and (3) total laparoscopic dissection and reconstruction. The entire relevant literature is either preliminary or consists of work in evolution presented at scientific meetings. Several generalizations are possible in a review of experience to date. First, these abdominal aortic reconstructions have been almost exclusively confined to patients undergoing repair for aortoiliac occlusive disease (AIOD) vs AAA. The reason for this is clear. Reconstruction for AIOD can be accomplished with a limited-field set-up at the site of the aortic anastomosis complemented by remote-access tunneling of graft limbs to the femoral arteries. The constraints on proximal aortic exposure in patients with AAA using minimally invasive methods and the need to at least control iliac arteries in AAA repair are additional factors. Second, laparoscopic aortic reconstruction has been difficult, principally related to the difficulties with bowel retraction and maintaining adequate aortic exposure. There continues to be debate about whether a transabdominal route with pneumoperitoneum or a retroperitoneal dissection is preferred. Most authors have related long operative times and significant technical difficulties and some have abandoned the laparoscopic approach. Barbera et al have recently presented data on 20 patients who underwent a variety of AIOD reconstruc-
tions via a totally transabdominal, laparoscopic approach. Their data, even allowing for the consideration that this was an initial experience, are sobering with respect to the basic question of whether these approaches decrease morbidity or facilitate postoperative recovery. Eleven patients underwent laparoscopic aortobifemoral bypass with a mean operative time of 4.5 hours and a postoperative hospital stay of 10 days! Overall, conversion to open repair was required in 17% of their patients.

Weber and Jako25 reported use of minimally invasive but open aortobifemoral bypass for AIOD. Specialized instrumentation permits an open proximal aortic anastomosis performed through a 10-cm incision with endoscopic-assisted graft limb tunneling to the groin. While the feasibility of this approach seems proven, considerations relative to adequate retroperitoneal coverage for the graft limbs are required.

Considerable clinical investigation is underway in the endovascular stent-graft repair of abdominal aortic lesions, and it is certain that an ever-increasing percentage of aortic lesions will be managed by endovascular methods. Further developments with merging of endovascular and conventional surgical methods are likely in the near future.

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REFERENCES


Surgical Anatomy

The sartorius arises side by side with the inguinal ligament from the tip of the anterior superior iliac spine. It inserts into the medial surface of the tibia below the level of the tubercle. In an adult it is usually 18 inches long and on contraction is shortened by six inches. This explains why the sartorius, which is the longest muscle in the body, requires so long a fleshy belly and why it needs a loose sheath in which to shorten and lengthen.