The development of minimally invasive cardiac surgical techniques in the last three years has been one of the most dramatic changes in the field of cardiology in some time. It is fair to say that although improvements and results are being published almost monthly in the cardiac surgery literature, these approaches are still in their infancy.

Access to the heart through small incisions (8–10 cm) has received a lot of attention and many patients as well as surgeons have learned about these operations from the lay press. In the past, surgeons tended to embrace new procedures as a group; in this case, there has been a significant level of resistance among some in the cardiac surgical community.1 The question raised over and over again is: Why should one change perfectly good and safe procedures?

The trend in other surgical specialties over recent years has been to minimize surgical trauma. The prevailing opinion seems to be that smaller is better. This concept contradicts the classical teaching of the French schools that believe that petit incision, petit chirurgien. Cardiac surgeons as a group have been slower than other specialists to adopt these techniques. The reason perhaps is that we are dealing with a moving target. A discrepancy exists in the cardiac surgical world as to what constitutes a “less invasive” procedure. While some believe that this is determined by the size of the incision, others think that it is a function of eliminating cardiopulmonary bypass as part of the procedure.2

Patients are motivated to have smaller incisions for aesthetic reasons, but also because their ability to return to conventional daily activities is unquestionably accelerated.3 The complete median sternotomy produces discomfort of the entire thoracic cage as the ribs are stretched laterally, affecting joints, costal cartilages, and occasionally the brachial plexus. In addition, although rare (1–2%), conventional median sternotomy exposes the anterior mediastinum to infection. Although the limited anterior thoracotomy is also painful, it affects patients in a more localized manner and, in general, for no more than 24–48 hours. The pain then settles without residual thoracic cage problems.

In order to understand the terminology of less invasive cardiac surgery, it is important to note that this term — as well as the term minimally invasive — has been rather loosely applied to a diverse variety of cardiac surgical procedures. These include:

1) coronary bypass surgery through conventional median sternotomy without the use of cardiopulmonary bypass (CPB);
2) coronary bypass surgery through small and even “keyhole” incisions on a beating heart without CPB and using direct vision, which is also known as minimally invasive direct coronary artery bypass (MIDCAB);
3) port-access coronary artery bypass utilizing a proprietary system that allows for conventional CPB with aortic cross-clamping and optimal myocardial protection while affording the opportunity of operating through a relatively small incision; and
4) aortic and mitral valve surgery utilizing a variety of novel approaches including the port-access system.

**Minimally invasive direct coronary artery bypass surgery (MIDCAB).** Coronary bypass surgery does not require the opening of the heart. The arteries in most instances are on the surface of the heart; for this reason, they can be targeted without extracorporeal circulation. This technique was explored by Ankeney in 1975, but failed to gain wide acceptance. Benetti in Argentina and Buffalø in Brazil led the way in demonstrating that this is possible by performing large numbers of coronary bypass procedures via conventional sternotomy without CPB. More recently, Calafiore in Italy, Robinson, Subramanian, Mack and Arom in the United States extrapolated these concepts and combined surgery without the pump with access through small incisions rather than median sternotomy. In doing so, these surgeons have essentially resurrected the operative procedure first described by Kolesov in 1967. Although this approach is possible, it is somewhat limiting since only the anterior lateral vessels of the heart are readily accessible and suitable candidates probably comprise less than 5 percent of coronary bypass patients. All of these techniques involve the performance of the coronary anastomosis on a beating heart. In spite of continuing improvement in cardiac stabilizing maneuvers, these operations are accomplished in less than optimal circumstances due to persistent cardiac motion, blood in the field, and the possibility of ischemic myocardial injury.

Surgeons advocating coronary surgery without CPB maintain that these techniques offer substantial cost savings not only in disposable equipment, but also because of a reduction in blood utilization and in neurologic injuries. The quality of the results following surgery without the use of CPB have been conflicting.

We feel that although coronary anastomosis with the heart beating may not be ideal, there exists a subset of patients in which the risk of performing a median sternotomy exceeds the risk of a less predictable MIDCAB. In our experience, this subset includes: 1) reoperations in a Jehovah Witness; and 2) second and third time reoperations in elderly patients with patient vein grafts. These patients had their critical lesions corrected with a single internal thoracic artery bypass to the left anterior descending coronary artery.

**Port-Access coronary artery bypass surgery.** While MIDCAB techniques continue to develop, the fact that immediate graft patency after MIDCAB is lower than expected in some hands has been a source of concern. Some surgeons believe that the quality of the distal anastomoses is compromised by not arresting the heart and attempting to suture conduits to recipient vessels without the benefit of a bloodless, motionless field. Methods have been developed (and systems are now being marketed) that can provide CPB, aortic cross clamping, and delivery of cardioplegia to facilitate surgery through small incisions. This approach has been commercially developed and marketed as Port-Access (Heartport, Inc., Redwood City, California), and is applicable to coronary as well as mitral valve surgery.

The Port-Access approach with full CPB, endovascular aortic occlusion, and cardioplegia delivery allows the surgeon to use standard anastomotic techniques on a still, protected heart. Because the distal anastomotic technique is not changed, this approach should achieve patency results that are similar to open chest methods if patients are selected appropriately. The early data from the Heartport Registry, a compulsory database registry, compares favorably with voluntary data collected by the Society of Thoracic Surgeons National Cardiac Surgical Database. These data show anastomotic patency rates of more than 97%, which is significantly higher than the reported patency rates with beating heart procedures. Ribakove et al. recently reported that the patency rate of left internal thoracic artery to left anterior descending artery anastomoses was 100% in 29 of 31 patients followed up angiographically. In addition, Port-Access has been used in a significant number of patients with multivessel disease for bypass grafting.

The goals of Port-Access heart surgery are less trauma and pain for the patient, shorter hospital stay and recovery time while providing an operation that is as safe and effective as standard surgery and transportable to the hands of most cardiac surgeons. The early results with the Port-Access technique suggest that these goals can be achieved with this system. Certainly, if Port-Access cardiac surgery is to be widely applicable, the operation must be as safe and efficacious as standard procedures performed through a median sternotomy.

**Less invasive mitral valve surgery.** Despite the development of durable prostheses for valve replacement and innovative reparative methods that re-establish the functional integrity of the valve, the surgical exposure of the mitral valve through a conventional median sternotomy has not changed substantially in over 30 years.

Growing experience with a limited thoracotomy approach to the mitral valve to avoid repeat median sternotomy for mitral reoperations has accumulated over the last decade. Navia and Cosgrove performed mitral valve surgery in 25 patients through a 10 cm right paraesternal incision by resection of the third and fourth costal cartilages and ligation of the right
internal thoracic artery using retrograde femoral perfusion without an operative mortality. They also described a partial sternotomy technique to expose the mitral and aortic valves.

Recently, several investigators have used video-assisted thoracoscopy to further decrease the incision size in mitral valve surgery.39–41 Most notably, Chitwood et al.41 reported their experience with “micro-mitral” valve repair through a 5 cm thoracotomy incision using video-assisted thoracoscopy. Peripheral CPB with retrograde cardioplegic arrest was established with the aid of a specially designed transthoracic aortic cross-clamp (Scanlan International, St. Paul, Minnesota), which was introduced through a separate incision in the posterior axillary line. Valve leaflet excision and mitral valve replacement were performed under camera/monitor visualization. The patient survived a cardiac arrest period of 165 minutes.

Early attempts at a less invasive approach to intracardiac surgery were limited by inadequate perfusion techniques and inability to provide myocardial protection and ventricular decompression. In 1993, Peters42 proposed a novel catheter-based apparatus that achieved effective CPB, cardioplegic arrest, and ventricular decompression. This catheter was later modified and provides the basis for the current Port-Access (Heartport, Inc., Redwood City, California) system.25–27,43–45

The safety of Port-Access mitral valve replacement with respect to myocardial preservation has been shown experimentally. Using a canine model, Schwartz et al.26 have demonstrated that Port-Access technology provides myocardial protection during aortic clamping that is equivalent to conventional CPB based on indexes of left ventricular contractility. Furthermore, after Port-Access mitral valve replacement and weaning from CPB, dogs showed full return of left ventricular function and transesophageal echocardiography demonstrated normal regional and global ventricular wall motion.46

Fann et al. reported on 10 patients who underwent Port-Access mitral valve procedures at Stanford University between May 1996 and January 1997.43 Five patients underwent mitral valve replacement and five had mitral repair. The average cross-clamp time was 99 minutes and average CPB time was 151 minutes. Mean ICU stay was 1.7 days and mean hospital stay was 4.3 days. All survived. One patient was reoperated at 3 months for perivalvular leak.

Based on early clinical experience, certain conclusions are evident. The average cross-clamp, CPB, and total operating room times are longer using the Port-Access approach than with conventional techniques of mitral valve replacement.43 A limited thoracotomy or access port requires no more (and likely less) time than a conventional sternotomy; however, the relatively deeper operative field for mitral valve procedures is associated with a distinct learning curve. Placement of the endo-aortic clamp, pulmonary artery vent and retrograde cardioplegia cannula require fluoroscopic guidance, thereby increasing the operating room time. With greater clinical experience, it is likely that the cross-clamp, CPB, and overall operating times will decrease.

Peri-operative complications associated with Port-Access mitral valve procedures have been reported in the early clinical experience.46 However, these complications cannot be considered unique to the Port-Access technique and occur with the conventional median sternotomy approach as well. Visualization of the mitral valve has been adequate in all cases using the Port-Access system; however, perivalvular leak has been detected in one case, which was likely the result of surgical technique. Other reported complications, such as postoperative hemorrhage requiring reexploration, occasionally occurs with standard cardiac surgery.

When using the Port-Access system, proper positioning of the endovascular aortic occlusion catheter is important because misplacement could potentially result in aortic valve incompetence and left ventricular distention, unequal distribution of cardioplegia, or compromised perfusion of the arch vessels. Another potential disadvantage is the inability to directly access the heart to ensure adequate de-airing after cardiotomy. Based on the early clinical experience using intraoperative transesophageal echocardiography, significant residual intracardiac air was not appreciated after the de-airing maneuvers, and there were no cases of postoperative neurological deficits that can be attributed to air embolism.

**Less invasive aortic valve surgery.** There have been three general operative approaches presented for minimally invasive aortic valve replacement. All three incisions are less than 10 cm in length and include the right parasternal incision, the “mini” sternotomy, and the transverse sternotomy.

The right parasternal incision described by Cosgrove48 is a 5–8 cm incision made in the upper right parasternal area. The second and third cartilages are exposed and resected. The right internal thoracic artery may be preserved and retracted laterally or divided. When the pericardium is opened and marsupialized to the wound edges, excellent exposure of the ascending aorta and right atrial appendage is obtained. Arterial cannulation may be directly into the distal ascending aorta or via the femoral artery. Venous cannulation may be via the superior vena cava and right atrium using suitably angled cannulae or via the femoral vein. On bypass, the patient is cooled to 28°C and the aorta is cross-clamped through the parasternal incision. With decompression of the right ventricle, the proximal aortic root is readily visible. Cardioplegic solution is
delivered directly into the coronary orifices. Traction on the commissure stitches placed in the aortic annulus provide improved exposure of the annulus. Venting is usually achieved through the annulus. De-airing is performed through an ascending aortic vent facilitated by partial aortic cross-clamping and careful transesophageal echo monitoring for residual air. Temporary pacing wires and a pericardial chest tube may be more readily placed prior to unclamping the aorta, while the heart structures remain decompressed.

The mini sternotomy approach has been popularized by Gundry. A 6–10 cm midline incision is made. The top of the sternum is exposed, the sternum is divided down to the third or fourth intercostal space, depending on the height of the aorta, and the incision is then “teed off” to the right side. This allows retraction of the upper sternum and manubrium so that the full extent of the aortic root can be exposed and manipulated. Cannulation, venting, and cardioplegic delivery is similar to that employed using the right parasternal approach, but exposure of the aorta is somewhat better. The right internal thoracic artery can be preserved in most cases.

Cosgrove has also advocated a transverse sternotomy incision. In this approach, a small transverse incision is made, both the right and the left internal thoracic arteries are divided, and a transverse sternotomy is made at approximately the third intercostal space. A retractor is then placed and the aorta is exposed by separating the upper and lower halves of the sternum. An advantage of this technique is the use of intrathoracic cannulation with the avoidance of femoral artery-femoral vein cannulation. One disadvantage is that both internal thoracic arteries are taken (although it is unusual to have to go back after aortic valve replacement for coronary artery bypass — less then 3% according to Cosgrove), so there is no possible utilization for future coronary bypass.

Cosgrove presented the first 50 minimally invasive aortic valve replacements using both the right parasternal and the transverse sternotomy. The surgical mortality rate was 2% and the post-operative morbidity rate was 10% (primarily from conversion to sternotomy, bleeding, and stroke). Comparing the costs between this method and conventional aortic valve surgery done in the same time period, they found that the cost was between 10% and 15% lower with the minimally invasive aortic valve replacement than in the conventional aortic valve replacement group.

Cohn et al. reported the results of aortic valve replacement via mini sternotomy in early 1997. There were no surgical deaths and decreases in length of stay, cost, and rehabilitation time.

Cohn et al. reported on 36 minimally invasive aortic valve replacements performed at the Brigham and Women’s Hospital. Both the mini-sternotomy and right parasternal approaches were used. A variety of valve prostheses were used. Four patients had reoperations. There were 2 surgical deaths. Excluding outliers (greater than 7 days), the average length of stay for 25 patients was 4 days. Other complications included 1 stroke, 1 postoperative bleed and 1 intraoperative dissection.

The early and mid-term results in all three minimally invasive approaches for aortic valve replacement are encouraging, and all show the following: a reduction of incisional pain; reduced requirement for post-hospital rehabilitation services; and improved mobility and return to full-time activity. This is advantageous in our cost-conscious world; when this is combined not only with the costs savings, but with improved patient satisfaction and the same quality of the surgical procedure itself, the advantages are clear.

Clinical experience with less invasive cardiac surgery. Our surgical experience with less invasive cardiac procedures began in November 1995. We have performed 71 operations involving the whole spectrum of coronary and valvular pathology. The procedural breakdown follows: 28 primary valve procedures; 14 aortic valve replacements (AVR); 8 mitral valve repairs; and 6 mitral valve replacements (MVR). There were 27 MIDCABs and 2 secundum atrial septal defect repairs. Four patients underwent re-operations (3 MIDCABs and 1 AVR). Four patients had multiple grafts via a small incision, femoral-femoral bypass, and conventional aortic cross-clamping. Six patients underwent surgery utilizing Port-Access technology. This included 5 multiple coronary artery grafting procedures and 1 mitral valve repair. There were no operative deaths. Perioperative complications included re-exploration for bleeding, wound infection and conversion to sternotomy early in the experience. There were no neurologic injuries. Two patients who had AVR with mechanical prostheses required pericardiocentesis approximately 3 weeks after discharge. Both were on coumadin. One MIDCAB patient who was converted to sternotomy sustained a perioperative infarction but was discharged on the fifth post-op day.

One patient whose left main coronary artery lesion was not appreciated and was thought to have isolated proximal left anterior descending disease returned 6 weeks after MIDCAB with recurrent angina. Repeat angiography showed a patent internal thoracic artery to left anterior descending artery anastomosis and significant left main disease. He underwent successful reoperation via conventional sternotomy and is doing well.

Comment. Less invasive methods offer the potential of less patient discomfort, less morbidity, and
lower overall cost. The Port-Access system is a catheter-based system that provides effective cardiopulmonary bypass, cardioplegic arrest, and ventricular decompression. This technique enables the surgeon to perform various cardiac procedures (coronary revascularization and intracardiac procedures) via smaller incisions in a still and bloodless field. Port-Access mitral valve procedures have been performed clinically with satisfactory outcome. Further experience in the clinical and research settings will lead to increased safety and efficacy of these newer techniques. We believe that the cardiac surgeon of the future will have a menu of options to access the heart in accordance with the patient’s anatomical needs.

REFERENCES


PANEL DISCUSSION

KENNETH KENT: Thank you very much for a wonderful demonstration. It is amazing how history repeats itself. Certainly in this country the early valve replacement was done with symptom bypass and there was also a paper I remember vividly in the early 1970s, the wide approach to microvalve repair, which was through the right atrium.

ALEX ZAPOLANSKI: The incisions were much larger, an actual thoracotomy. I must say that femoral cannulation is not free of trouble. In the initial experience with Heartport, a modest number of retrograde dissections were reported. This is a function of the patients’ peripheral vascular disease. I would recommend to the cardiologists in the room to study the aorto-iliac bifurcation at the conclusion of the angiogram to assist surgeons in these cases.

BILL O’NEILL: Our surgeons are more enamored with the beating heart technique — they say it is probably better to keep the patients out for bypass. You didn’t really comment much about that. There is a whole school of thought that deals with non-cardioplegic arrest and decreasing the morbidity that occurs with the heart and lung machine. Could you please comment on that?

DR. ZAPOLANSKI: I’d be happy to. The only surgery that can be done off bypass is coronary surgery. Valves and intracardiac congenital defects are eliminated. Yes, I believe in it, but the quality of these anastomoses may not be consistent. Tom Linneimer alluded to the fact that some anastomoses do not look perfect. The leaders in the field — Subramaninan and Calafiore — had problems. I recently operated on a 100 kilogram man whose left anterior descending artery (LAD) was deeply embedded in the septum. I felt I had to put him on bypass to be able to dissect the LAD, control bleeding, etc. I do not believe that every patient can be done off the pump. The ultimate decision has to be made in the operating room. We have treadmills on 85–90% of our patients post-operatively and so far all of them have been negative.

JUAN PARODI: Alex, I would like to ask you a few questions. How many patients do you think would be suitable for this technique? Was the patient that you showed a perfect case or a good candidate for PTCA? For example, from my own experience, I would never send this patient to surgery. The technique in the video that you showed looked very difficult. As a conventionally trained surgeon, how do you adjust your training and how did you feel with this kind of surgery?

DR. ZAPOLANSKI: I was, of course, very uneasy at the beginning. I had done many cases off bypass with the sternum open. A lot of instrumentation, such as CTS, OMNI, and the one I am developing with KAPP Surgical, is being developed to stabilize the heart. One has to choose the cases appropriately as you do with intervention. In the future, we will be able to do multiple grafting through small incisions with Heartport. I believe one of the surgeons in Asheville, North Carolina is doing 70% of the coronary cases with a minimally invasive approach.

ASHOK DHAR: I would like to mention the complaint of a cardiac surgeon in Calcutta while doing a CABG on a patient following in-stent stenosis 3 months following PTCA. He found significant thickening of the arterial wall adjacent to the stented segment, making it difficult for the incision and suturing process. I would like to take this opportunity to hear about your experience with this, if any.

HOWARD COHEN: I have had no experience of that nature. Frankly, I’ve never seen a stent in the operating room. I have, however, done many patients that have had previous stenting, but there is no other option.

SPEAKER: I congratulate Dr. Zapolanski on his excellent technique and results. I think one of the
things in our experience that has been important is that it requires a surgeon to be committed to the technique. It is not a technique that you can do once every few weeks and be proficient. In our institution, we have essentially one surgeon who is doing the operation. He performs the procedure many times a week and we feel a lot of confidence in referring patients to him. I would certainly agree that you need to have a menu; sometimes you get in and can’t do the operation that you had planned — although I think the patient has to understand that. We found that you can follow patients by doing post-operative Doppler assessment of the mammary arteries; with successful mammary bypass, you can clearly see diastolic predominance of the Doppler flow when you put the Doppler on the mammary arteries externally in the second intercostal space. You can compare the left with the right and you can also check coronary flow reserve by giving intravenous adenosine. You see a marked increase in the diastolic predominance in the Doppler flow in the left internal flowing intravenous adenosine.

DR. ZAPOLANSKI: I just want to make one final remark. I am very committed to the operation too because that is what I am doing. I want to point out that at a meeting in New York about a year ago, the most committed surgeons in the world attended. They did 7 operations. All patients were taken to the cath lab on the same day or the next day. I think 3 or 4 of the anastomoses were either closed or narrowed. These surgeons are leading the country and the world with these procedures. You need a commitment, but you know some cases are anatomically impossible to approach this way and these cases should be done with conventional bypass.