Endoscopic mitral valve repair: Feasible, reproducible, and durable

Filip P. Casselman, MD, PhD, FETCS
Sam Van Slycke, MD
Helge Dom, MD
Dave L. Lambrechts, MD
Yvette Vermeulen, MSc
Hugo Vanermen, MD, FETCS

Casselmann and Vanermen (left to right)

From the Department of Cardiovascular and Thoracic Surgery, OLV Clinic, Aalst, Belgium.

Read at the Eighty-second Annual Meeting of The American Association of Thoracic Surgery, Washington DC, May 5-8, 2002.

Received for publication June 4, 2002; revisions requested Aug 20, 2002; revisions received Sept 9, 2002; accepted for publication Sept 17, 2002.

Address for reprints: Filip P. Casselman, MD, PhD, FETCS, Department of Cardiovascular and Thoracic Surgery, OLV Clinic, Moorselbaan 164, 9300 Aalst, Belgium (E-mail: Filip.Casselmann@olvz-aalst.be).

J Thorac Cardiovasc Surg 2003;125:273-82

Copyright © 2003 by The American Association for Thoracic Surgery

0022-5223/2003 \$30.00+0

doi:10.1067/mtc.2003.19

Objective: We sought to document the feasibility, safety, and effectiveness of performing mitral valve repair using a totally endoscopic approach.

Methods: Between February 1997 and October 1, 2001, 187 patients underwent totally endoscopic mitral valve repair at our institution. The mean age was 60.7 ± 13.1 years, and 62% were male. Median preoperative functional class and degree of mitral regurgitation were II and 4, respectively. Data collection included an institutional protocol assessing procedure-related pain, cosmesis, and functional recovery. Statistical analysis included Kaplan-Meier and Cox regression methods. Mean follow-up was 19 ± 15.2 months and was 100% complete.

Results: Associated atrial procedures were performed in 9.1% ($n = 17$) of the patients. Two patients required intraoperative conversion to sternotomy. Thoracoscopic re-evaluation for suspected bleeding ($n = 19$) was part of our aggressive postoperative management. One patient required sternotomy for control of bleeding. Hospital mortality included 1 (0.5%) patient and was not technology related. There were 1 early and 6 late reoperations, 4 of which were due to endocarditis. No risk factors for repair failure could be detected. Freedom from mitral valve reoperation at 4 years was $93.3\% \pm 2.6\%$. The median degree of mitral regurgitation at follow-up was 0. Ninety-three percent of the patients were highly satisfied with either no or mild postoperative pain, and 98.4% believed they had an aesthetically pleasing scar.

Conclusions: Totally endoscopic mitral valve repair can be done safely with excellent results and a high degree of patient satisfaction. It is now our exclusive approach for isolated atrioventricular valve disease.

In 1994, Heartport, Inc (currently part of Johnson & Johnson Corp, New Brunswick, NJ), developed a technique for minimally invasive cardiac surgery. The technique consists of an endo-cardiopulmonary bypass (EndoCPB) system, which is connected through the femoral artery and vein. The heart is arrested by using an endoaortic clamp and antegrade cardioplegia administration, retrograde cardioplegia administration, or both. Initial dog studies demonstrated the feasibility and safety of the technique for both

TABLE 1. Preoperative mitral valve characteristics (n = 187)

Variable	N	%
Grade of regurgitation		
2 +	1	0.5
3 +	58	31.0
4 +	128	68.4
Valve pathology		
Degenerative	156	83.4
Fibroelastic deficiency	149	79.7
Barlow disease	7	3.7
Endocarditis	14	7.5
Sole annular dilatation	16	8.6
Congenital	1	0.5
Carpentier functional classification		
Type 1	17	9.1
Type 2	167	89.3
Posterior prolapse	136	72.7
Anterior prolapse	21	11.2
Prolapse of both leaflets	10	5.3
Type 3	3	1.6

coronary artery bypass and mitral valve surgery.¹⁻⁵ Clinical experience confirmed this feasibility but also pointed out an important learning curve and some technique-related major adverse events.⁶ This attenuated the initial enthusiasm of several centers.

In 1997, Heartport, Inc, obtained authorization from European regulators for investigational clinical application of its EndoCPB system. This meant the start of our clinical program, and we have since used this technology for a variety of indications. The majority of applications, however, were mitral valve repair procedures. This article analyzes our experience with mitral valve repair using the EndoCPB system.

Methods

Between February 1997 and October 1, 2001, a total of 402 procedures were performed with the EndoCPB system (Johnson & Johnson Corp) at our institution. Of these, 187 (46.5%) were mitral valve repair procedures performed by a single surgeon (H.V.), and this group constitutes the subjects of this study. This group of 187 patients represents 66.1% of all mitral valve repair procedures not combined with coronary artery bypass grafting at the OLV Clinic during the same time period. Initially, only simple repair procedures and low-risk patients were considered for this technique. As experience grew, more complex repair cases and higher-risk patients were also considered candidates for this technique. Currently, any mitral valve repair case, either isolated or combined with tricuspid valve disease or atrial septal defect (ASD), is approached with this technique.

All patients were preoperatively fully informed about the technique and were able to choose a standard median sternotomy if that was their preference.

Patients

The mean age of the patients was 60.7 ± 13.1 years (range, 27-84 years), and 62% were male (n = 116). Comorbidity was present in 113 (60.4%) patients and included atrial fibrillation in 40 (21.3%) patients, arterial hypertension in 57 (30.5%) patients, chronic obstructive pulmonary disease in 15 (8%) patients, peripheral vascular disease in 2 (1.1%) patients, and insulin-dependent diabetes in 1 (0.5%) patient. Preoperative New York Heart Association functional class was I in 33 (17.6%) patients, II in 72 (38.5%) patients, III in 67 (35.8%) patients, and IV in 15 (8%) patients. Left ventricular function was normal in 136 (72.7%) patients, mildly impaired in 40 (21.4%) patients, moderately impaired in 8 (4.3%) patients, and severely impaired in 3 (1.6%) patients. The mean preoperative left ventricular end-diastolic diameter was 58.6 ± 7.14 mm (range, 32-79 mm). The mean preoperative left ventricular end-diastolic volume index was 104.3 ± 32 mL/m² (range, 44-196 mL/m²). The left ventricle was preoperatively not dilated in 54 patients.

Preoperative mitral valve disease is detailed in Table 1. The patient with grade 2+ regurgitation had an associated ASD. The Carpentier classification was used to describe valve dysfunction.⁷ The median preoperative degree of mitral valve regurgitation was 4. All procedures were primary and elective interventions. In 2 patients the endoscopic mitral valve repair procedure was part of a hybrid approach. Percutaneous transluminal coronary angioplasty and stenting of the right coronary artery (n = 1) and left anterior descending artery (n = 1) were both performed before the valve procedure.

Postoperatively, chest tubes were routinely kept for 48 hours (or longer if chest tube output remained sanguineous), regardless of whether bleeding stopped earlier and fluid became serous. Postoperative analgesia consisted of 10 mg of intravenous piritramide (Dipidolor; Janssen-Cilag, Beerse, Belgium) and 10 mg of intramuscular piritramide at the time sedation was stopped in the intensive care unit. Once the patient was extubated, analgesics were only given at the request of the patient. The patients were anticoagulated with fenprocoumon (Hoffmann, Grenzach-Wyhlen, Germany) for 3 months and were then switched to acetylsalicylic acid unless they were in atrial fibrillation.

Surgical Technique

After achievement of general anesthesia, the patient is placed in the supine position, with slight elevation of the right hemithorax. All patients are ventilated with a double-lumen endotracheal tube. A right radial arterial line is inserted. Next, a 14F or 17F DLP cannula (Medtronic DLP, Grand Rapids, Mich) is placed percutaneously by the anesthesiologist through the internal jugular vein into the superior vena cava. This is performed under transesophageal echocardiographic (TEE) guidance.

The right common femoral artery and vein are exposed by using an oblique groin incision. A double pledget U stitch (4-0 polytetrafluoroethylene*) is placed at the anterior side of the common femoral artery, and a double purse-string suture (4-0 polytetrafluoroethylene) is placed at the anterior side of the common femoral vein.

*Gore-Tex; registered trademark of W. L. Gore & Associates, Flagstaff, Ariz.

Figure 1. Operative setup. All ports have been made. Note the central working port, the camera port, and the venting port; the shaft that will hold the left atrial retractor has also been introduced in the chest (see text for details).

An anterolateral working port of 4 to 6 cm is made in the midportion of the right inframammary groove, usually the fourth intercostal space. A medium soft tissue retractor is inserted, but no other rib retractor is used. A camera port is also made in the fourth intercostal space but at the level of the anterior axillary line. Just before the introduction of the camera, the right lung is deflated. At the beginning of the procedure, a 0° camera is used, which is switched to a 30° downward-looking camera once the left atrium is opened and retracted. A venting port is made in the seventh intercostal space at the level of the anterior axillary line; this port also serves for carbon dioxide insufflation once the left atrium is opened. A left atrial blade retractor is introduced into the right side of the chest through the working port and connected to a 2-mm shaft penetrating the chest wall in the fourth intercostal space, just lateral to the right internal thoracic artery. When the right hemidiaphragm precludes a direct view on the left atrium, a pledget-supported stitch is used to pull the dome down through the seventh intercostal space (Figure 1).

The patient is heparinized, and the femoral vessels are cannulated with a Seldinger technique. TEE is used to precisely introduce and position the venous cannula (21F-25F) into the right atrium at the junction with the inferior vena cava. Next, the arterial cannula (21F-23F) is introduced, also by using the Seldinger technique. The endoaortic balloon is positioned from the groin, with TEE guidance, in the ascending aorta just above the sinotubular junction. We always used the endoaortic balloon and have no experience with the endo-direct transthoracic balloon cannula. CPB with kinetic assisted venous drainage is instituted during TEE monitoring. Once the pericardium is opened and the interatrial groove is dissected, the endoaortic balloon is progressively inflated with TEE guidance, carefully checking its position at the level of the sinotubular junction. Once the balloon is approximately three

fourths inflated, the heart is arrested by means of rapid injection of 10 mL (0.25 mg/kg) of adenosine (Sanofi-Winthrop, Notre Dame de Bondeville, France). Immediately thereafter, the balloon is further inflated, and cold crystalloid antegrade cardioplegic solution is administered. While the endoaortic balloon is being inflated, the right radial pressure should remain the same at all times because any decrease in pressure might indicate a malpositioning of the balloon (partially) occluding the brachiocephalic artery. The volume of saline solution needed to inflate the balloon is dependent of the size of the ascending aorta. The balloon pressure is kept at approximately 350 mm Hg. During the remainder of the procedure, an additional dose of 300 mL of cold crystalloid antegrade cardioplegic solution is administered every 30 minutes. The aortic root pressure is continuously measured and is usually between 0 and 30 mm Hg in the absence of cardioplegia administration. Its value needs to be constant because a sudden increase of aortic root pressure indicates a nonocclusive balloon. The left atrium is opened, and the mitral valve is exposed with the left atrial blade. The operative field is flooded with carbon dioxide and cleared of blood by using the venting suction, which is positioned in the left inferior pulmonary vein.

First, the annuloplasty stitches are placed, starting with the first stitch at the anterolateral commissure. Next, 2 annuloplasty stitches are placed on the anterior leaflet annulus just medial of the anterolateral commissural stitch. Now all remaining annular stitches are placed along the remaining annulus, starting at the anterolateral commissural stitch, over the posterior annulus toward the posteromedial commissure and then the medial portion of the anterior leaflet annulus. All annular stitches are exteriorized through the working port and fixed in suture guides. This maneuver exposes the mitral valve completely.

Figure 2. A flail P2 segment is resected endoscopically by using the sliding technique.

Figure 3. Final repair result after a triangular resection in the A3 segment. The annuloplasty stitches are in place, but the ring is not yet in place.

Now the valve is analyzed according to the Carpentier guidelines.⁷ Posterior leaflet mitral valve repair is performed by using the Carpentier techniques (Figure 2).⁷ Shafted instruments are introduced in the chest and the left atrium through the working port. The repair is performed with the exclusive aid of video assistance. Knots are thrown extracorporeally and tightened with a knot pusher. Anterior mitral leaflet prolapse is corrected with a small triangular resection⁸ or with the creation of new polytetrafluoroethylene chords,⁹ depending on the extent of the prolapsing area. Once the repair is completed (Figure 3), the left atrium is closed, leaving the venting suction in place for deairing. In addition, suction is applied to the tip of the endoaortic balloon, and the left lung is inflated before final closure of the left atrium. A bipolar ventricular pacing wire (Bipolar pacing lead; Medtronic France, Fourmies, France) is placed before unclamping because it is otherwise almost impossible to place. The aorta is unclamped, and reperfusion is allowed. The valve repair is tested under TEE guidance just before termination of CPB. Careful hemostasis is performed after protamine hydrochloride (Roche, Fontenay-sous-Bois, France) administration, and 2 drains are left in situ: 1 intrapericardial and 1 intrathoracic. Both drains are exteriorized through an existing port. The pericardium is approximated, and the working port and groin are closed intracutaneously.

Follow-up

All patients were seen at the outpatient clinic 2 months postoperatively, except patients who were operated on in October 2001. They were then sent back to their referring cardiologists, who saw their patients at 4 months and then usually yearly. Follow-up was performed between August and November 2001. All patients and their general practitioner, as well as the referring cardiologist, were contacted to obtain clinical information and echocardiographic follow-up data. The official guidelines were used to complete a follow-up questionnaire.¹⁰ In addition to this information, patients were asked about the amount of pain they experienced at the time of the operation; they were also questioned about how fast they had regained professional or expected activity postoperatively, whether they were pleased with the aesthetic result of the operation, and whether they would prefer this technique again if they were to choose between EndoCPB and standard median sternot-

omy. The mean patient follow-up was 19 ± 15.2 months (range, 0.2-54.1 months) and was 100% complete. A total of 284 patient-years was available for analysis. The New York Heart Association functional class in 184 survivors at follow-up was class I in 149 patients, class II in 30 patients, and class III in 5 patients. At follow-up, 156 patients were in normal sinus rhythm, 20 were in atrial fibrillation, and 8 had pacemaker rhythm.

Assessment of Repair and Durability

All patients had immediate intraoperative postrepair TEE to assess the repair. Repair durability was primarily assessed by the incidence of reoperation. In addition, the latest echocardiographic follow-up was analyzed to detect the presence of mitral regurgitation. It was available in 178 of 180 patients who retained their native valves at the time of follow-up. The mean echocardiographic follow-up was 14.9 ± 14.7 months (range, 0.1-53.8 months).

Data Analysis

The design of the study was retrospective, and data are expressed as means $\pm$ SD. Survival and event-free estimates were determined by means of Kaplan-Meier analysis¹¹ and expressed as proportions $\pm$ SE. Analysis was performed with the Statistica package, Release 5.1 (StatSoft, Tulsa, Okla).

Risk factors for outcome were evaluated by using the Cox proportional hazard models. The first event was used as the outcome. First analyses were performed by using only the risk factor of interest in the Cox univariate model. Because none of the risk factors showed a statistical significance of less or equal to 0.10, no further multivariate Cox regression model could be applied. The potential risk factors entered into the analysis of reoperation are listed in the appendix.

Estimates of the linearized incidence rate with corresponding SEs were obtained by dividing the number of events by the corresponding patient-years of follow-up. The SE was calculated as the square root of the incidence divided by the patient-years of follow-up, assuming a Poisson distribution.

TABLE 2. Mitral valve repair techniques used in the present series (n = 187)

Valve repair technique	N	%
Posterior leaflet quadrangular resection	134	71.7
Posterior leaflet sliding plasty	68	36.4
Anterior leaflet triangular resection	9	4.8
Anterior leaflet PTFE neochochordae	17	9.1
Resection of both leaflets	4	2.1
PTFE neochochordae of both leaflets	3	1.6
Chordal shortening	3	1.6
Chordal transfer	1	0.5
Calcium debridement	6	3.2
Commissuroplasty		
Anterolateral	1	0.5
Posteromedial	1	0.5
Annuloplasty		
Type		
Carpentier-Edwards Physio ring	183	97.9
Carpentier-Edwards Classic ring	4	2.1
Size		
28	22	11.8
30	32	17.1
32	39	20.9
34	61	32.6
36	29	15.5
38	4	2.1

PTFE, Polytetrafluoroethylene.

Results

Immediate Technical Feasibility

The operative technique was successfully performed in all but 2 patients. These 2 patients were operated on early in the series and required intraoperative conversion to median sternotomy. In one patient aortic dissection occurred intraoperatively. This was repaired by using standard techniques. The patient, however, had a stroke with residual hemiplegia. The other conversion to median sternotomy was done because of the inability to reach adequate bypass flow through the common femoral artery. This patient underwent standard mitral valve repair and recovered uneventfully.

The techniques used to perform mitral valve repair are depicted in Table 2. Associated procedures were performed in 17 patients: tricuspid annuloplasty in 6 (3.2%) patients, atrial arrhythmia ablation in 6 (3.2%) patients, ASD in 3 (1.6%) patients, tricuspid annuloplasty and atrial arrhythmia ablation in 1 (0.5%) patient, and a fibroelastoma of the aortic valve in 1 (0.5%) patient. Mean aortic crossclamp and CPB times were 91.4 ± 23.7 minutes (range, 24-160 minutes) and 131.3 ± 28.0 minutes (range, 74-215 minutes), respectively.

Postoperative Course and Complications

One 71-year-old patient required a reintervention for failure of mitral valve repair on postoperative day 1. This was done through a median sternotomy, and valve replacement was

TABLE 3. Perioperative and postoperative complications (other than death and reintervention, n = 187)

Type of complication	N	%
Pneumonia	2	1.1
Prolonged ventilation (>72 h)	10	5.4
Subcutaneous emphysema	7	3.7
New-onset atrial fibrillation	30	16
Pacemaker implantation	4	2.1
Myocardial infarction	1	0.5
Renal insufficiency	3	1.6
Neurologic event	1	0.5
Peripheral ischemic event	0	0
Deep venous thrombosis	0	0
Wound infection	0	0
Groin lymphocele	12	6.4
Postoperative drainage of right pleural effusion	4	2.1

performed. The patient, however, had a low cardiac output syndrome and died on postoperative day 5. This was the only 30-day mortality in the series (0.5%).

Postoperative reintervention (through the same operative approach) for suspected bleeding was performed in 19 patients. Reintervention was performed as soon as the chest tube output exceeded 100 mL/h for 3 hours. Consequently, an active bleeding source was found in only 9 instances. In one patient, however, a median sternotomy had to be performed to control the bleeding, which was located at the pacemaker insertion. Other postoperative morbidity is depicted in Table 3. Of note is that there were no neurologic events other than the one in the patient who underwent aortic dissection, no wound infections (neither at the working port nor in the groin), and no deep venous thromboses after femoral vein cannulation.

The mean postoperative chest tube output was 1223 ± 1115 mL (median, 750 mL); 61.5% of the patients had a total chest tube output of less than 1000 mL. Bleeding was secondary to abnormal clotting factors in 19.3% of the patients. The mean transfusion rate was 3.7 ± 4.5 units per patient (range, 0-25 units; median, 2 units), and 25.7% of the patients did not receive a transfusion. The mean intensive care unit stay was 35.4 ± 25.4 hours (median, 23 hours), with 68.5% being discharged within 24 hours and an additional 18.2% within 48 hours. The mean hospital stay was 8.4 ± 4.8 days (median, 7 days), with 71.1% of the patients discharged within 8 days.

Durability of the Repair

Reoperation. As stated earlier, there was one early failure of repair requiring reoperation on postoperative day 1. In addition, there were 6 late reoperations at a mean of 13.9 ± 7.1 months after the initial procedure. Causes of reoperation were endocarditis in 4 patients and recurrent mitral valve regurgitation in 2 patients (in one patient reop-

Figure 4. Freedom from mitral valve reoperation.

eration was necessitated by progressive left ventricular dilatation after myocardial infarction). All these patients underwent valve replacement with median sternotomy used as the surgical approach. The patient undergoing early reoperation died on postoperative day 5. No other patient died at reoperation. The freedom from mitral valve reoperation was $99.5\% \pm 0.5\%$ at 30 days, $97.1\% \pm 1.4\%$ at 1 year, and $93.3\% \pm 2.6\%$ at 4 years (Figure 4). The linearized incidence rate was $2.5\% \pm 0.06\%$ per patient-year. No risk factors for repair failure could be detected univariately. Consequently, a multivariate risk factor analysis could not be performed.

Echocardiographic follow-up. Late echocardiographic follow-up was available in 178 (98.9%) of the 180 patients with retained native mitral valves at the time of follow-up (in the 2 late-death patients we included the last TTE before death). Mean echocardiographic follow-up was 14.9 ± 14.7 months. The median degree of mitral valve regurgitation was 0. A total of 116 (64.4%) patients had no residual mitral valve regurgitation, 48 (26.7%) patients had 1+ regurgitation, and 12 (6.7%) patients had 2+ regurgitation. Two patients had 3+ mitral valve regurgitation at follow-up. They are currently asymptomatic and closely monitored.

Other Follow-up Events

One early death and 2 late deaths occurred. One patient died suddenly on postoperative day 49, and another patient died on postoperative day 497 after a cholecystectomy. Survival was $99.5\% \pm 0.5\%$, $98.9\% \pm 0.8\%$, and $97.8\% \pm 1.3\%$ at 30 days, 1 year, and 4 years postoperatively, respectively (Figure 5). The linearized incidence rate for death was $1.0\% \pm 0.03\%$ per patient-year.

As stated earlier, one patient with aortic dissection had a stroke with permanent residual hemiplegia. During follow-

up, another 16 anticoagulation-related complications occurred. Three of these were second events. None of these events resulted in permanent neurologic damage. The linearized incidence of anticoagulation-related complications was $5.1\% \pm 0.08\%$ per patient-year. Freedom from the first anticoagulation-related complication was $98.9\% \pm 0.8\%$, $93.8\% \pm 2.0\%$, and $84.2\% \pm 4.8\%$ at 30 days, 1 year, and 4 years postoperatively (Figure 6).

Four patients had endocarditis during follow-up at a mean of 13.2 ± 7.4 months postoperatively. These patients all had recurrent mitral valve regurgitation and were reoperated on by using a median sternotomy. All of them underwent valve replacement. Freedom from endocarditis was $100\% \pm 0\%$, $98.4\% \pm 1.1\%$, and $95.9\% \pm 2.1\%$ at 30 days, 1 year, and 4 years postoperatively. The linearized incidence was $1.4\% \pm 0.04\%$ per patient-year.

Patient Satisfaction

Procedure-related pain. Of all patients, 93.5% stated they experienced minimal to almost no procedure-related pain. None of the remainder mentioned excessive procedure-related pain.

Postoperative recovery. Of patients, 33.7% were back at work or at routine activity within 4 weeks postoperatively. Another 26.6% were back at this activity level within 8 weeks postoperatively. Patient age did not influence postoperative recovery ($P = .14$).

Cosmesis. An overwhelming 98.4% of the patients were extremely pleased with the cosmetic result of the procedure. In 41.9% of the patients, the scar was hardly visible any more.

Choose again? In 92.4% of the patients, the patient would choose the same procedure if he or she was to face the same operation again.

Figure 5. Postoperative survival.

Figure 6. Freedom from anticoagulation-related complications.

Discussion

“Surgery is exposure” is a statement that many of us heard constantly during our surgical training. In minimally invasive cardiac surgery, exposure is still of paramount importance but is now created intrathoracically and visualized through video assistance. This requires a definite learning curve and a different surgical attitude from the surgeon and his or her assistant. In fact, both need to adopt the 4 major changes characterizing this technique: the use of the EndoCPB system and endo-clamp; the use of shafted instruments; video assistance as the surgeon’s eye; and TEE for supervision of the entire procedure. Indeed, every step of the procedure, from catheter insertion to the final surgical

result, is controlled by TEE. Previously, our group and others have stressed the usefulness and necessity of preoperative TEE guidance by an experienced person.¹²⁻¹⁶

The present series, which includes our initial experience and thus our learning curve, demonstrates that the procedure can be safely performed with good results. The 30-day mortality in this series was 0.5%, a figure comparing favorably with those of some of the major classic mitral valve repair studies¹⁷⁻¹⁹ and with that of another initial experience report.⁶ Our learning period did, however, include one aortic dissection. This 0.5% occurrence is lower than the initial experience of Mohr and colleagues⁶ but higher compared with that of other groups.²⁰⁻²² To avoid this complication,

we suggest that our cardiologists inject the right iliac artery at the time of heart catheterization to identify iliac artery stenosis.

The smallest femoral artery cannula available is a 21F cannula. The femoral artery therefore needs to be able to fit this cannula and provide adequate flow, a condition that was not fulfilled in one of our patients. To date, we have been unable to correlate inadequate femoral size to another parameter, such as body surface area. However, in addition to severe peripheral vascular disease, a small femoral artery is clearly a contraindication for the use of the EndoCPB system. Other contraindications include excavated pectus (this condition substantially reduces the anteroposterior diameter of the chest and displaces the heart to the left, both of which preclude direct access to the left atrium), aortic regurgitation of greater than grade 1 (precluding the use of antegrade cardioplegia administration), severely atherosclerotic ascending or descending aorta (which dramatically increases the stroke risk with endovascular manipulation), and dense adhesions in the right hemithorax.

Although others demonstrated a lower blood transfusion ratio in minimally invasive procedures versus standard sternotomy,²³⁻²⁵ our high reintervention rate, median chest tube output, and transfusion rate do not seem to be so favorable. Introducing this technique in 1997, we were extremely cautious and anticipated a markedly reduced blood loss because of reduced tissue trauma. Therefore, we aggressively took patients back by using the same operative approach but found an active bleeding source in only half of the patients. In all other cases, the right hemithorax was rinsed, and cloths were evacuated. Also, all chest tubes remained in place for 48 hours, even when bleeding had stopped after a few hours postoperatively and chest tube output was just serous fluid. This of course also negatively influenced the total amount of chest tube drainage. On the other hand, we do have a very liberal use of blood products, which is reflected in the low transfusion-free proportion of the study population. In addition, quite a high proportion (19.3%) required correction of coagulation parameters, presumably related to the relatively long pump run. Nevertheless, we changed a few things during the study period to reduce excessive bleeding: the pericardial fat is now resected only if it avoids direct approach to the left atrium, and the pacemaker wire is now always placed on the inferior side of the left ventricle, where the thicker muscle avoids a muscle tear caused by the pacemaker wire.

One might argue that the presented surgical technique is not a totally endoscopic procedure because a working port is made. This 4- to 6-cm incision could be used by the surgeon to directly look inside the chest. This working port, however, is only made to permit instrument handling and introduction of an annuloplasty ring. We only use the soft tissue retractor and never spread the ribs, as is done by some other

groups.^{25,26} The soft tissue retractor is used to minimize postoperative pain but, at the same time, forces the surgeon to look at the screen, thereby totally relying on video assistance for the entire procedure. We therefore consider the procedure totally endoscopic.

The freedom from mitral valve reoperation in the present series was $93.3\% \pm 2.5\%$ at 4 years (Figure 4). This is lower than previously reported in other series of degenerative valve disease, where the same percentage of freedom from mitral valve reoperation is reached at approximately 10 years.^{17,18} However, only 3 of the 7 reoperations were due to failed mitral valve repair. The 4 others were due to endocarditis. In fact, the linearized incidence rate for endocarditis was $1.4\% \pm 0.04\%$, which is rather high. We do not know why the incidence of endocarditis in the present series was so high, but it definitely influenced our reoperation rate negatively.

Patient satisfaction in the present series was very high. More than 98% of the patients were extremely pleased with the cosmetic result of the procedure. Forty-two percent even stated they could hardly see the scar any more. Also, procedure-related pain was very favorably assessed in greater than 93% of the patient cohort, and no patients reported excessive postoperative pain. Other authors also reported favorable postprocedural pain perceptions, both with the current technique²⁷ and after other minimally invasive mitral valve surgical techniques.^{26,28} In addition, almost 34% of the patients were fully recovered within 4 weeks. Faster recovery of patients undergoing minimally invasive operations versus that of patients undergoing standard sternotomy was demonstrated by Glower and coworkers.²⁴ In the present series an additional 27% of the patients fully recovered within 8 weeks postoperatively. All these factors undoubtedly contributed to the high patient satisfaction rate. Almost 93% of the patients would prefer the same operative technique if they were to start all over again.

Finally, one might consider endoscopic mitral valve repair by using video assistance, a transition phase toward robotic mitral valve surgery.²⁹ Although mitral valve repair without the use of a working port has recently been reported,³⁰ we do not feel the need for such a device in mitral valve surgery. Using the current technique, we are able to repair complex cases and have never felt the absence of voice-controlled devices or extra robot-controlled surgical tools to be a shortcoming.

In conclusion, the present series demonstrates the feasibility, reproducibility, and medium-term durability of the EndoCPB technique for mitral valve repair. The technique provides ample patient satisfaction and is currently our technique of choice for isolated atrioventricular valve disease.

The major limitation of this study is its retrospective nature. Although the general cardiac surgery data are pro-

spectively collected in our database, the more specific procedure-related data were retrospectively collected. However, we hardly encountered missing data, presumably because of our high interest in this procedure.

The retrospective nature of the study might have positively influenced the procedure-related pain sensation because patients were asked about procedure-related pain at the time of follow-up. Because the majority of the patients were very satisfied with the procedure and the cosmetic result, periprocedural pain sensation might have been judged more positively than would have been the case if patients were interviewed immediately postoperatively. This is not the case for the postoperative recovery period because this was checked with specific dates or events for every patient.

A prospective randomized trial would be the best approach to truly evaluate the (positive) effect of this operative technique versus a standard median sternotomy approach. However, this is impossible to realize in our center because patients are specifically referred for the endoscopic technique and therefore unwilling to participate in a randomized trial.

References

- Stevens JH, Burdon TA, Siegel LC, Peters WS, Pompili MF, Goar FG, et al. Port-access coronary artery bypass with cardioplegic arrest: acute and chronic canine studies. *Ann Thorac Surg.* 1996;62:435-41.
- Pompili MF, Stevens JH, Burdon TA, Siegel LC, Peters WS, Ribakove GH, et al. Port-access mitral valve replacement in dogs. *J Thorac Cardiovasc Surg.* 1996;112:1268-74.
- Schwartz DS, Ribakove GH, Grossi EA, Stevens JH, Siegel LC, Goar FG, et al. Minimally invasive cardiopulmonary bypass with cardioplegic arrest: a closed chest technique with equivalent myocardial protection. *J Thorac Cardiovasc Surg.* 1996;111:556-66.
- Stevens JH, Burdon TA, Peters WS, Siegel LC, Pompili MF, Vierra MA, et al. Port-access coronary artery bypass grafting: a proposed surgical method. *J Thorac Cardiovasc Surg.* 1996;111:567-73.
- Schwartz DS, Ribakove GH, Grossi EA, Buttenheim PM, Schwartz JD, Applebaum RM, et al. Minimally invasive mitral valve replacement: Port-Access technique, feasibility, and myocardial functional preservation. *J Thorac Cardiovasc Surg.* 1997;113:1022-31.
- Mohr FW, Falk V, Diegeler A, Walther T, van Son JAM, Autschbach R. Minimally invasive Port-Access mitral valve surgery. *J Thorac Cardiovasc Surg.* 1998;115:567-76.
- Carpentier A. Cardiac valve surgery—the “French correction.” *J Thorac Cardiovasc Surg.* 1983;86:323-37.
- Fasol R, Joubert-Hubner E. Triangular resection of the anterior leaflet for repair of the mitral valve. *Ann Thorac Surg.* 2001;71:381-3.
- David TE, Omran A, Armstrong S, Sun Z, Ivanov J. Long-term results of mitral valve repair for myxomatous disease with and without replacement with expanded polytetrafluoroethylene sutures. *J Thorac Cardiovasc Surg.* 1998;115:1279-86.
- Edmunds LH, Clark RE, Cohn LH, Grunkemeier GL, Miller DC, Weisel RD. Guidelines for reporting morbidity and mortality after cardiac valvular operations. *Eur J Cardiothorac Surg.* 1996;10:812-6.
- Kaplan EL, Meier P. Nonparametric estimation from incomplete observations. *J Am Stat Assoc.* 1958;53:457-81.
- Coddens J, Deloof T, Hendrickx J, Vanermen H. Transesophageal echocardiography for Port-Access surgery. *J Cardiothorac Vasc Anesth.* 1999;13:614-22.
- Falk V, Walther T, Diegeler A, Wendler A, Autschbach R, van Son JAM, et al. Echocardiographic monitoring of minimally invasive mitral valve surgery using an endoaortic clamp. *J Heart Valve Dis.* 1996;5:630-7.
- Siegel LC, St Goar FG, Stevens JH, Pompili MF, Burdon TA, Reitz BA, et al. Monitoring considerations for Port-Access cardiac surgery. *Circulation.* 1997;96:562-8.
- Applebaum RM, Cutler WM, Bhardwaj J, Colvin SB, Galloway AC, Ribakove GH, et al. Utility of transesophageal echocardiography during Port-Access minimally invasive cardiac surgery. *Am J Cardiol.* 1998;82:183-8.
- Mohr FW, Onnasch JF, Falk V, Walther T, Diegeler A, Krakor R, et al. The evolution of minimally invasive mitral valve surgery—2 year experience. *Eur J Cardiothorac Surg.* 1999;15:233-9.
- Gillinov AM, Cosgrove DM, Blackstone EH, Diaz R, Arnold JH, Lytle BW, et al. Durability of mitral valve repair for degenerative disease. *J Thorac Cardiovasc Surg.* 1998;116:734-43.
- Deloche A, Jebara VA, Relland JYM, Chauvaud S, Fabiani JN, Perier P, et al. Valve repair with Carpentier techniques—the second decade. *J Thorac Cardiovasc Surg.* 1990;99:990-1002.
- Cohn LH, Couper GS, Aranki SF, Rizzo RJ, Kinchla NM, Collins JJ Jr. Long-term results of mitral valve reconstruction for regurgitation of the myxomatous mitral valve. *J Thorac Cardiovasc Surg.* 1994;107:143-51.
- Gulielmos V, Dangel M, Solowjowa N, Wagner FM, Karbalai P, Schmidt V, et al. Clinical experiences with minimally invasive mitral valve surgery using a simplified Port Access technique. *Eur J Cardiothorac Surg.* 1998;14:141-7.
- Chaney MA, Nikolov MP, Tuckek M, Bakhos M. An institution's initial experience with Port-Access minimally invasive cardiac surgery. *J Cardiothorac Vasc Anesth.* 1998;12:617-9.
- Grossi EA, LaPietra A, Ribakove GH, Delianides J, Esposito R, Culliford AT, et al. Minimally invasive versus sternotomy approaches for mitral reconstruction: comparison of intermediate-term results. *J Thorac Cardiovasc Surg.* 2001;121:708-13.
- Cohn LH, Adams DH, Couper GS, Bichell DP, Rosborough DM, Sears SP, et al. Minimally invasive cardiac valve surgery improves patient satisfaction while reducing costs of cardiac valve replacement and repair. *Ann Surg.* 1997;226:421-8.
- Glower DD, Landolfo KP, Clements F, Debruijn NP, Stafford-Smith M, Smith PK, et al. Mitral valve operation via Port Access versus median sternotomy. *Eur J Cardiothorac Surg.* 1998;14:S143-7.
- Grossi EA, Galloway AC, Ribakove GH, Zakow PK, Derivaux CC, Baumann FG, et al. Impact of minimally invasive valvular heart surgery: a case-control study. *Ann Thorac Surg.* 2001;71:807-10.
- Chitwood WR, Wixon CL, Elbeery JR, Moran JF, Chapmann WHH, Lust RM. Video-assisted minimally invasive mitral valve surgery. *J Thorac Cardiovasc Surg.* 1997;114:773-82.
- Walther T, Falk V, Metz S, Diegeler A, Battelini R, Autschbach R, et al. Pain and quality of life after minimally invasive versus conventional cardiac surgery. *Ann Thorac Surg.* 1999;67:1643-7.
- Aklog L, Adams DH, Couper GS, Gobeze R, Sears S, Cohn LH. Techniques and results of direct-access minimally invasive mitral valve surgery: a paradigm for the future. *J Thorac Cardiovasc Surg.* 1998;116:705-15.
- Felger JE, Chitwood WR, Nifong LW, Holbert D. Evolution of mitral valve surgery: toward a totally endoscopic approach. *Ann Thorac Surg.* 2001;72:1203-9.
- Mehmanesh H, Henze R, Lange R. Totally endoscopic mitral valve repair. *J Thorac Cardiovasc Surg.* 2002;123:96-7.

Appendix

Potential Risk Factors (Variables)

Demography

- Age at repair
- Sex
- New York Heart Association functional class

Mitral valve disease

- Prolapse of anterior leaflet
- Prolapse of posterior leaflet
- Chordal rupture of anterior leaflet

Chordal rupture of posterior leaflet

Annular dilatation

Barlow disease

Left atrial diameter

Left ventricular function-dimension

Grade of left ventricular dysfunction

History of myocardial infarction

Left ventricular dilatation

Comorbidity

Preoperative atrial fibrillation

Insulin-dependant diabetes mellitus

Arterial hypertension

Chronic obstructive pulmonary disease

Peripheral vascular disease

Renal failure

Repair

Leaflet resection

Sliding leaflet repair

Chordal shortening

Use of neochordae

Discussion

Dr Delos M. Cosgrove (*Cleveland, Ohio*). Drs Vanermen and Casselman are to be congratulated on excellent results that they have reported using a small right anterior thoracotomy and endoscopic visualization. Their report demonstrates a very low operative mortality rate and advantages in terms of cosmesis and minimal amounts of pain. However, these have not been achieved without a very significant learning curve, prolongation of aortic crossclamp and cardiopulmonary times, and a 10% incidence of reintervention for bleeding. It is of interest that only two thirds of mitral valve repairs during this period were undertaken in this manner, thus suggesting a limitation in the applicability of this method.

We have experience with this approach and compared it with a limited anterior sternotomy. In a pilot study we were unable to demonstrate clinical advantages when compared with a limited sternotomy. We did, however, note an increased equipment expense of \$5000 and significantly longer operating room time.

I have a few questions for the authors. Is this approach applicable to all diseases of the mitral valve? If so, what percentage of all your primary isolated mitral valve operations are performed with these techniques?

Second, what are the cost implications considering the increased equipment costs and presumed longer operating room times?

Finally, would you recommend that this technique be adopted universally as a standard practice for mitral valve surgery?

Dr Vanermen: Thank you very much, Dr Cosgrove, for your questions. Your points are very well taken because I think that is

what it is all about when it comes to implementation of new technology. There is a lot of new technology coming up in the 21st century. We should be able to recognize which might be useful and which might not, and that is the first step.

The second step is procedural development. That is the most difficult part, and I can tell you that in this case it was blood, sweat, and tears. Therefore, in the beginning it would have been unwise to adapt this technique to every abnormality of the mitral valve. Not everyone in our team adopted the technique, and we started with the easy cases. At this very moment, we would treat all isolated mitral valve abnormalities this way.

The learning curve was difficult, and I am not predictive enough to say when all mitral valve surgery will be endoscopic. I hope that will be the case one day for the patients. But the learning curve is difficult, and people should not commit the same mistakes and encounter the same obstacles we encountered in the beginning of our experience. At a certain moment beyond the learning curve, this should become a routine operation, and then the teaching commences. We hope that it will be generally used one day.

As far as cost is concerned, there is no evidence thus far that the undoubtedly higher in-hospital cost is compensated for by the absence of procedure-related pain, the absence of scar-related problems, and the faster rehabilitation.

Dr F. W. Mohr (*Leipzig, Germany*). Dr Vanermen, I would like to congratulate you for your pioneering work. As you well know, we do have our own experience with that procedure in about 600 patients, and we have eliminated the cost concerns from Toby Cosgrove by eliminating the balloon after 200 patients and just using a straightforward crossclamp, transthoracic clamp, which had a significant effect also on neurologic problems.

I just have one question for you, which I think you failed to mention, concerning the advantage of such procedures in redo operations, patients who had previous coronary bypass surgery, and patients who had previous aortic valve replacements. Could you comment on this aspect too?

Dr Vanermen: Your point is very well taken, Dr Mohr. It is true, and this is an extremely valuable technique in all those cases when patients actually had sternotomy or redo sternotomy already and had thoracic grafts in front of their ascending aorta. If you had to go to the mitral valve then, it becomes easy if you apply this endoscopic technique and if you go through a very small right lateral thoracotomy. In those patients the balloon obviously is extremely useful, too. And I can imagine that sometimes you can clamp the aorta with a transthoracic clamp. Through the small incision I have made, it is impossible to actually control the bleeding site on the ascending aorta if something occurs when you withdraw your aortic cannula or when you withdraw your cardioplegic cannula in the ascending aorta.