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Original Article

Single-Center Experience with Minimally Invasive Mitral Operations through Right Minithoracotomy

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Background: To report single-institution experience with minimally invasive mitral valve operations through the right minithoracotomy over a 5-year period.
Methods: Patients who underwent minimally invasive mitral valve surgery (MIMVS) between January 2012 and December 2016 were included. Clinical follow-up data were collected in a prospective database and analyzed retrospectively.
Results: Data from 151 patients were assessed (mean age, 63.4 ± 9.7 years; 55% were females). Overall 30-day mortality was 0.7% (n = 1). Mean operating time, cardiopulmonary bypass, and aortic cross-clamp times were 254.9 ± 48.7, 140.5 ± 36.1, and 94.8 ± 27.0 minutes, respectively. Associated procedures were tricuspid valve annuloplasty (37.1%, n = 56) and closure of atrial septal defect (6.0%, n = 9). Cryoablation was performed in 43.7% of patients (n = 66). One patient (0.7%) required conversion to median sternotomy and six patients (4.0%) underwent re-explorations due to bleeding. Median postoperative hospital stay was 12 days. Overall survival at 5 years was 94.1% ± 2.0%. Freedom from reoperation was 94.6% ± 2.9% at 5 years.
Conclusions: MIMVS is a feasible, safe, and reproducible approach with low mortality and morbidity. Mitral valve surgery through a small thoracotomy is a good alternative to conventional surgical access.

Keywords: minimally invasive, minithoracotomy, mitral valve, mitral valve repair, endoscopic surgery

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Introduction

Minimally invasive cardiac surgery has become increasingly popular, and several techniques for minimally invasive mitral valve surgery (MIMVS) have been developed in recent decades. The use of MIMVS through the right minithoracotomy has been facilitated by new technologies for cardiopulmonary bypass, special surgical instruments, and the use of video-thoracoscopic assistance. Compared with conventional sternotomy, MIMVS has shown excellent results in terms of a reduction in morbidity, surgical trauma, pain, and shorter hospital stay, as well as enabling faster recovery, an earlier return to full activities, superior preservation of lung function, and

improved cosmetic results.[1] MIMVS was initiated at our center in January 2012. The purpose of this study was to review our results with endoscopic approach in mitral valve surgery and to examine the feasibility, safety, and effectiveness of MIMVS. The study depicts the technical aspects of the procedures and postoperative outcome and demonstrate also feasibility of technically demanding mitral valve repairs and combined procedures in MIMVS.

Materials and Methods

Data were collected from patients undergoing elective MIMVS through a right anterolateral small thoracotomy between January 2012 and December 2016. The study complies with the Declaration of Helsinki and the ethical committee of our institute approved the study (reference number: 201708 S10P). Individual consent for the study was waived due to the retrospective nature. Signed informed consent with the operation procedure was obtained from each patient. Preoperative transesophageal echocardiography was performed in all patients. The severity of mitral valve regurgitation was according to the recommendation of the European Association for Cardio-Thoracic Surgery.[2] Indications for concomitant surgical cryoablation were based on the HRS/EHRA consensus statement for catheter and surgical ablation of atrial fibrillation. Patients were indicated for ablation in case of symptomatic atrial fibrillation refractory to at least one Class I or II antiarrhythmic medication or with symptomatic atrial fibrillation prior to initiation of antiarrhythmic therapy and with maximal left atrial diameter of less than 60 mm.[3]

Echocardiographic follow-up was conducted in all survivors who had received a postoperative echocardiogram >3 months after surgery. Follow-up data on survival and reoperation were collected from hospital database or by phone contact with patients, and supplemental information supplied from referring cardiologist and family physicians. Survival data were also obtained from health insurance database. Clinical and transthoracic echocardiographic (TTE) follow-up was collected by means of clinical examination in our outpatient clinic.

Contra-indications for surgery were as follows: dilated ascending aorta (>40 mm), aortic regurgitation >grade 1, peripheral vascular disease, ascending aorta calcifications, and severe right pleural adhesions.

Surgical technique

Patients were intubated with a single lumen endotracheal tube. After general anesthesia was instituted, the superior vena cava was cannulated percutaneously (Fem-FlexII, Edwards Lifesciences Inc., Irvine, CA, USA) via the right jugular vein to obtain adequate venous return. Right minithoracotomy (5–7 cm) was performed at the 4th intercostal space. A soft tissue retractor (ValveGate Soft Tissue Retractor, Geister, Tuttlingen, Germany) was inserted. Additional incisions (5–10 mm) were used for video assistance, the left atrial retractor, and the transthoracic aortic clamp. The right femoral artery and vein were exposed and a venous cannula (QuickDraw, Edwards Lifesciences Inc.) was inserted through the femoral vein into the right atrium. Correct positioning was achieved under transesophageal echocardiographic guidance. The femoral artery was cannulated using an arterial cannula (Fem-FlexII, Edwards Lifesciences Inc.). The ascending aorta was clamped with a Chitwood clamp. In reoperation procedures, endoaortic balloon occlusion was used. An antegrade cold crystalloid cardioplegia (Custodiol-CE, Dr. Franz Köhler Chemie, Bensheim, Germany) was delivered directly into the ascending aorta by a needle vent catheter. The mitral valve was approached with a traditional left paraseptal atriotomy and exposed using a specially designed atrial retractor. A video camera (5 mm, 30°) was placed through a 5 mm port in the 4th intercostal space. The procedure was performed under direct vision with video assistance. Three surgeons contributed to this series.

Statistical analysis

Data are expressed as mean ± standard deviation (median, interquartile range [IQR]), and categorical data are expressed as frequencies or ratios. Testing of variables was compared by paired *t* test. Survival and freedom from reoperation were estimated with the standard nonparametric Kaplan–Meier method. A p value <0.05 was considered significant. Statistical analysis was performed with NCSS 11 Statistical Software 2016 (NCSS, LLC, Kaysville, UT, USA).

Results

From January 2012 to December 2016, 151 elective MIMVS were performed in our department. Baseline patient characteristics are summarized in **Table 1**. The mean age was 63.4 ± 9.7 years, 55% were females (n = 83), and two patients (1.3%) had previous cardiac surgery. In all, 49 (32.5%) patients were in New York Heart Association (NYHA) functional class III and IV. The mean grade of mitral valve regurgitation at presentation was 3.7 ± 0.5.

Table 1 Preoperative patient characteristics

Variables	Patients (n = 151)
Age (years)	63.4 ± 9.7
Gender (female)	83 (55.0%)
BMI (kg/m^2)	27.6 ± 4.6
LVEF (%)	57.5 ± 12.2
Diabetes mellitus	17 (11.3%)
Arterial hypertension	109 (72.2%)
COPD	15 (9.9%)
Hyperlipidemia	70 (46.4%)
Atrial fibrillation	70 (46.4%)
Redo procedure	2 (1.3%)
EuroScore II (%)	2.2 ± 1.7
Creatinine concentration (µmol/L)	84.5 ± 19.3
NYHA class	2.1 ± 0.9
I	26 (17.2%)
II	77 (51.0%)
III	49 (32.5%)
IV	0 (0%)
Mitral valve regurgitation grade	3.7 ± 0.5
3+	38 (25.2%)
4+	111 (73.5%)
Tricuspid valve regurgitation grade	
3+	23 (15.2%)
4+	23 (15.2%)
Mitral valve pathology	
Degenerative	126 (83.4%)
Rheumatic	4 (2.6%)
Carpentier´s functional class	
Type I	72 (47.7%)
Type II	56 (37.1%)
Type IIIa	2 (1.3%)
Type IIIb	21 (13.9%)

BMI: body mass index; COPD: chronic obstructive pulmonary disease; LVEF: left ventricle ejection fraction; NYHA: New York Heart Association

The techniques used to perform mitral valve repair are depicted in **Table 2**. An annuloplastic ring (Carpentier-Edwards Physio, Edwards Lifesciences, Inc.) was implanted in all patients who underwent mitral valve repair procedure. Associated procedures were tricuspid valve annuloplasty (37.1%, n = 56) and closure of atrial septal defect (6.0%, n = 9). Cryoablation was performed in 43.7% of patients (n = 66). In mitral valve replacement patients (n = 11), a bioprosthesis (Perimount Plus, Edwards Lifesciences, Inc.) was implanted in six patients and a mechanical valve (Medtronic Open Pivot Heart Valve, Medtronic, Inc., Minneapolis, MN, USA) was implanted in five. Mean operating time, cardiopulmonary bypass, and aortic cross-clamp times were 254.9 ± 48.7, 140.5 ± 36.1, and 94.8 ± 27.0 minutes, respectively.

Table 2 Intraoperative data

Variables	Patients (n = 151)
CPB time (minutes)	140.5 ± 36.1
Aortic cross-clamp time (minutes)	94.8 ± 27.0
Operative time (minutes)	54.9 ± 48.7
Mitral valve repair (n = 140)	
Lone ring implantation	90 (64.3%)
Annuloplasty ring size	29.3 ± 3.3
Leaflet resection	7 (5.0%)
Gore-Tex chordae implantation	47 (33.6%)
Mitral valve replacement (n = 11)	
Biological valve	6 (54.5%)
Mechanical valve	5 (45.5%)
Concomitant procedure	
Tricuspid annuloplasty	56 (37.1%)
Closure of atrial septal defect	9 (6.0%)
Cryoablation	66 (43.7%)

CPB: cardiopulmonary bypass

Early outcomes

Overall 30-day mortality was 0.7% (n = 1; predicted median EuroScore II, 1.7%; range, 0.5–9.1). The patient manifested with myocardial ischemia in the early postoperative period. The angiography confirmed the circumflex coronary artery occlusion. Although the percutaneous intervention was performed immediately, the patient underwent myocardial infarction. Mean postoperative ventilation time was 12.7 ± 12.2 hours (median 9.0; IQR, 7.0–13.1); duration of intensive care unit stay was 48.0 ± 38.8 hours (median 43.5; IQR, 22.0–68.7), and postoperative hospital stay was 15.2 ± 10.0 days (median 12; IQR, 10.0–17.0).

One patient (0.7%) required conversion to median sternotomy because of severe aortic valve regurgitation due to injury of aortic valve. This was created by the stich for annuloplasty ring implantation going through the aortic leaflets (between the right and non-coronary cusp). The patient underwent aortic valve plasty using a pericardial patch; no aortic valve regurgitation was observed during follow-up (**Table 3**).

All patients had uneventful thoracic wound healing, with the exception of four patients (2.6%) who developed intercostal lung herniation, all of which required surgical repair. A lymph fistula or lymphocele was observed in the groin of seven patients (4.6%); two patients with groin lymphocele required revision of the surgical wound in the groin. Re-exploration was performed in six patients (4.0%) as a result of bleeding. In all cases, the revision was possible through the same minithoracotomy, and in one patient the introduction of cardiopulmonary bypass was required. Bleeding sources included intercostal artery

Table 3 Postoperative and follow-up results

Complications			
Renal replacement therapy		3 (2.0%)	
Cerebrovascular stroke		4 (2.6%)	
Pneumonia		10 (6.6%)	
Re-exploration for bleeding		6 (4.0%)	
Groin lymphocele		7 (4.6%)	
Atrial fibrillation		65 (43%)	
Wound infection		0 (0.0%)	
Conversion to sternotomy		1 (0.7%)	
Peripheral ischemic event		0 (0.0%)	
Re-expansion pulmonary edema		4 (2.6%)	
Results of clinical and echocardiographic follow-up			
Variables	Preoperative	Follow-up	p value
NYHA class	2.1 ± 0.9	1.3 ± 0.6	<0.001
Variables	Discharge	Follow-up	p value
Mean transvalvular gradient in repairs (mm Hg)	4.6 ± 1.6	4.0 ± 1.9	<0.001
Mitral valve regurgitation in repairs (grade)	0.4 ± 0.6	0.9 ± 0.9	<0.001
LVEF (%)	55.6 ± 13.1	56.8 ± 11.7	n.s.

LVEF: left ventricle ejection fraction; NYHA: New York Heart Association

in four, cardioplegic cannulation site in one and left atrial suture line in one. The incidence of stroke and acute renal replacement therapy was 2.6% (n = 4) and 2.0% (n = 3), respectively. We did not observed patients who suffered of acute limb ischemia as we had performed angio-computed tomography (CT) of the aorta and femoral arteries in all patients and we had contraindicated patients with peripheral vascular disease. Our practice is to strictly cannulate common femoral artery above the deep femoral artery. In our study, we observed two patients (1.3%) who developed clinical symptoms of acute lung injury with re-expansion pulmonary edema (RPE). Longer time of postoperative ventilation was needed to overcome respiratory failure. In two patients (1.3%) radiographically evident signs of RPE was detected without any clinical consequences. At discharge, in mitral valve repair patients, residual mitral regurgitation was classed as none (66.4%, n = 93), grade 1 (27.1%, n = 38), grade II: (5.0%, n = 7), or grade III (1.4%, n = 2).

Patient survival

Mean survival follow-up was 2.9 ± 1.5 years. There were seven late deaths. Kaplan–Meier estimates of overall survival, including operative deaths, showed that the cumulative 1-, 3-, and 5-year survival rates of the 151 patients were 95.9% ± 1.6%, 94.1% ± 2.0%, and 94.1% ± 2.0%, respectively. (**Fig. 1**).

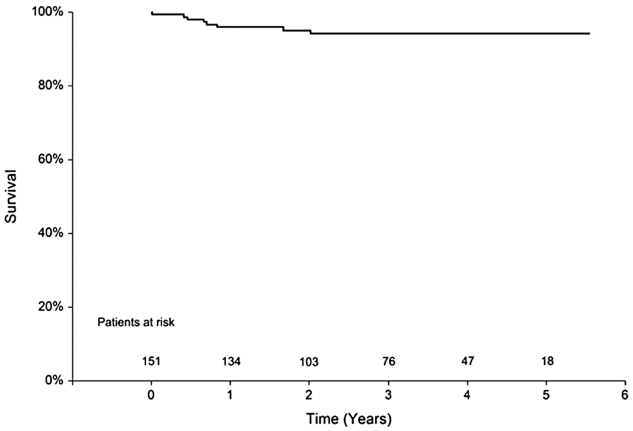

Fig. 1 Kaplan–Meier curve for overall survival.

Reoperation

Five patients required reoperation during the follow-up period. Four patients returned with mitral regurgitation after previous mitral valve repair. Two patients underwent replacement with either a biological or mechanical prosthetic valve. In two patients with the annuloplasty ring dehiscence, we performed re-repair in terms of re-fixation of the ring. One patient underwent uncomplicated reoperation due to endocarditis of the biological valve.

Overall freedom from reoperation was 98.0% ± 1.1%, 97.0% ± 1.5%, and 94.6% ± 2.9% at 1, 3, and 5 years, respectively (**Fig. 2**).

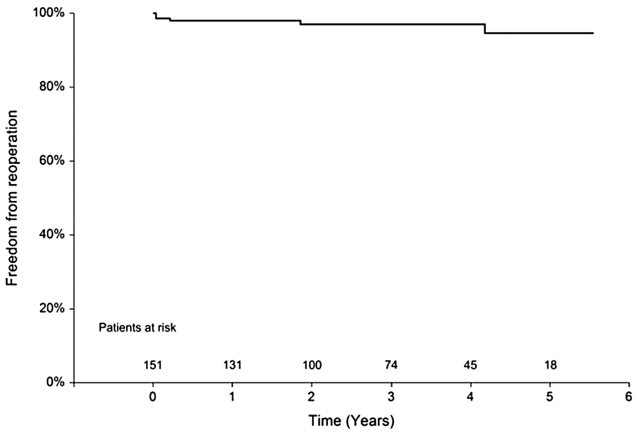

Fig. 2 Kaplan–Meier curve for overall freedom from reoperation.

Clinical and echocardiographic results and follow-up

Mean clinical and echocardiographic follow-up was 320.5 ± 310.8 days (median: 127; IQR, 104–303), and was completed in 98.6% of surviving patients (n = 143). Regarding clinical status, a significant symptomatic improvement in NYHA functional class was evident, with mean improvement being from 2.2 ± 0.7 preoperatively to 1.3 ± 0.6 at follow-up (p <0.001) (**Table 3**). At the time of follow-up control, the success rate of surgical cryoablation was 77.3% (51 from 66 patients were free of atrial fibrillation).

Echocardiographic examination was performed in all patients before discharge and at clinical follow-up. Patients with repaired valves had mean mitral transvalvular gradients 4.6 ± 1.6 mmHg at discharge and 4.0 ± 1.9 mmHg at follow-up (p <0.001). The grade of mitral valve regurgitation was significantly reduced postoperatively, with the mean postoperative mitral valve regurgitation value being 0.4 ± 0.6 versus the preoperative value of 3.7 ± 0.5 (p <0.001) (**Table 3**).

Discussion

Minimally invasive approaches have been used with increasing frequency for heart valve surgery in recent decades, and MIMVS is associated with excellent efficacy and good long-term results.[4] Overall 30-day mortality in our series was 0.7%, which is lower than the 1.7% mortality predicted by EuroScore II. Finally, in the setting of mitral valve repair, the mean postoperative mitral valve regurgitation value averaged 0.4 ± 0.6. We demonstrated comparable results with respect to postoperative survival and reoperation. Kaplan–Meier analysis revealed a 95.9% ± 1.6% and 94.1% ± 2.0% overall survival at 1 and 5 years, respectively. Freedom from reoperation was 98.0% ± 1.1% and 94.6% ± 2.9% at 1 and 5 years, respectively. These data were consistent or lower than the results reported in Society of Thoracic Surgeons Database (STS) and by some groups in Europe for conventional approach through the sternotomy. Gammie et al. reported result from STS database. Operative mortality was 1.4% in mitral valve repair group.[5] Perier et al. published operative mortality of 2.9% for the mitral valve repair of posterior leaflet prolapse. The survival rate at 6 years was 87% and the freedom from reoperation was 95%.[6] Another large study by Suri et al. assessed 1411 patients with isolated mitral regurgitation. The freedom from reoperation was 93% at 5-year follow-up.[7]

We reported similar results to previous published studies on MIMVS. Glauber et al. reported in-hospital mortality of 1.1%, the overall survival at 10 years was 88%, and the freedom from reoperation was 94%.[4] Seeburger et al. from Leipzig group published 2.4% 30-day mortality. The Kaplan–Meier estimate for survival at 5 years was 82.6% and for freedom of reoperation was 96.3%.[8] Assessment of our patient cohort demonstrated that MIMVS is a safe procedure and follow-up results indicated that this surgery provides satisfactory results in the treatment of mitral valve disease associated with low incidence of intraoperative complications and excellent postoperative outcomes.

In 2010, the results of a meta-analysis conducted by the International Society of Minimally Invasive Cardiothoracic Surgery (ISMICS) were published.[9,10] This study evaluated the results of mitral valve surgery performed via a small thoracotomy versus results obtained using sternotomy. The most important finding of this meta-analysis was a statistically comparable 30-day perioperative mortality, therefore representing the first publication to describe the safety of MIMVS. The meta-analysis concluded that MIMVS may be an alternative to conventional mitral valve surgery, given the comparable short- and long-term mortality, comparable risk of postoperative complications (renal, pulmonary, cardiac, gastrointestinal), comparable reoperation rate, reduced sternal complications and blood transfusions, lower incidence of postoperative atrial fibrillation, shorter intensive care unit (ICU) stay, and shorter length of postoperative hospital stay.

The quality of surgical repair is a frequent concern regarding MIMVS. In the present study, the use of MIMVS was associated with a mitral valve repair rate of 94%, accompanied by a high success rate. Consistent with previous reports on endoscopic mitral valve surgery, the rate

and success of mitral repair was not compromised by the less invasive approach.[1,4,8] In addition, low mitral valve regurgitation grade was seen postoperatively (0.4 ± 0.6 at discharge).

Our exclusion criteria for MIMVS included those who had undergone a previous right thoracotomy, as adhesions of the lung make dissection of the mediastinum a significant challenge. In addition, an atherosclerotic process of the ascending aorta or severe atherosclerotic involvement of the pelvic and femoral arteries compromises the safety of the procedure. For these reasons, we recommend performing angio-CT of the aorta and femoral arteries in all patients. Where atherosclerosis is evident, some authors advocate the use an alternative approach for cannulation, that is, central cannulation of the ascending aorta or axillary artery.[4]

Over the years, mitral valve repair has been shown to demonstrate significantly better survival rates than mitral valve replacement.[11] Several different mitral valve repair techniques have been developed, many of which have been successfully applied through a minimally invasive approach. Despite the fact that all conventional mitral valve repair techniques can be performed with great precision through a small access, our group adopted a principle of so-called "respect rather than resect."[12] This techniques consist of the use of expanded polytetrafluoroethylene (ePTFE) neochordae, which supports the free edge of prolapsing segments of the mitral valve.[13] A modification of this technique using premeasured ePTFE loops (the "loop" technique) was introduced by the Leipzig group to effectively simplify the repair procedure, thereby improving reproducibility.[14] As we gained more experience with the "loop" technique and observed satisfactory intraoperative and echocardiographic results, implantation of Gore-Tex neochordae became our procedure of choice. In this study, Gore-Tex implantation was used in 84% of patients with prolapsing leaflet of the mitral valve, and an original "resection" technique was used in 12.5% of patients with leaflet prolapse.

We observed a rare complication, de novo aortic valve incompetence after mitral valve repair, in one patient.[15] We hypothesize that this may have resulted from iatrogenic aortic cusp injury caused by a suture from the ring implantation. We therefore advise that great care should be taken when stitching at the base of the anterior leaflet of the mitral valve during minimally invasive surgery. In this patient, conversion to sternotomy was required and the aortic cusp was repaired using a pericardial patch; aortic valve regurgitation was not seen during follow-up.

Some reports raised concern about the potential increased risk of stroke associated with MIMVS. It is therefore of note that in the present study four patients (2.6%) experienced postoperative stroke. A higher incidence of stroke is usually explained by the difficulty in dearing of heart chambers, by the retrograde blood flow in the descending aorta or by longer duration of cardiopulmonary bypass. However, in propensity-matched comparisons published by Svensson and colleagues, by Holzhey and associates and recently by Lange et al., no differences in the incidence of thromboembolic events were seen.[16–18]

A number of previous studies demonstrated the significant clinical benefits of minimally invasive approaches. Santana et al. conducted a retrospective study of minimally invasive surgery in patients with chronic obstructive pulmonary disease.[19] Patients treated with a minimally invasive approach had lower hospital-related mortality than patients undergoing sternotomy (1% versus 5%) and a significantly lower incidence of all postoperative complications (30% versus 54%, $p = 0.002$). The shorter length of stay in the intensive care unit (47 versus 73 hours, $p < 0.001$) and the shorter length of postoperative hospitalization (6 versus 9 days, $p < 0.001$) emphasize the benefit of the minimally invasive approach. In another study, Santana and colleagues investigated the benefit of a less invasive approach versus sternotomy in obese patients (body mass index [BMI] >30 kg/m^2).[20] More postoperative complications were noted in the sternotomy group, with a higher incidence of acute renal failure, longer intubation time, more frequent reintubation, higher mortality or a higher incidence of deep wound infections. A low risk of conversion from minithoracotomy to sternotomy was previously described by Vollroth et al.[21] In this study, which evaluated data from MIMVS in 3125 patients, it was necessary to proceed to conversion in only 1% of cases. The experience with MIMVS in patients after previous cardiac surgery, in reoperations, was described by Seeburger et al., who demonstrated a 30-day mortality rate of 6.6% (in 77% patients ventricular fibrillation was used).[22] The benefit of MIMVS in reoperations was also reported by Casselman and colleagues, who demonstrated a total operative mortality of 3.8% and a 1-year survival rate of 93.6% ± 2.8%.[23] In this study, the so-called port-access approach was routinely used. These data suggest that right lateral minithoracotomy could be not only feasible in cases requiring reoperation but is also associated with a lower than predicted mortality rate. Indeed, the feasibility of MIMVS has also been described in patients with multiple previous cardiac operations.[24]

Finally, Holzhey et al. conducted a propensity-matched comparison to analyze the results of a less invasive approach in elderly patients >70 years of age.[17] No differences were seen between 30-day mortality (7.7% versus 6.3%, p = 0.82) and combined cardiac and cerebrovascular complications (11.2% versus 12.6%, p = 0.86).

Limitations

This study had several limitations, including its retrospective design with inherent bias in data collection, in addition to its single-center design and the fact that no information was recorded regarding the cause of late mortality. Finally, a longer period of follow-up (mainly clinical follow-up) would be required to report long-term survival and treatment success.

Conclusion

MIMVS is a feasible, safe, and reproducible approach with low mortality and morbidity.

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Disclosure Statement

The authors report no conflict of interest.

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