European Journal of Cardio-thoracic Surgery 34 (2008) 943—952

EUROPEAN JOURNAL OF CARDIO-THORACIC SURGERY

www.elsevier.com/locate/ejcts

Review

Minimally invasive mitral valve surgery: a systematic review and meta-analysis

Paul Modi, Ansar Hassan, Walter Randolph Chitwood Jr. *

East Carolina Heart Institute, Greenville, NC, USA

Received 23 May 2008; received in revised form 19 July 2008; accepted 28 July 2008; Available online 30 September 2008

Summary

The mitral valve has been traditionally approached through a median sternotomy. However, significant advances in surgical optics, instrumentation, tissue telemanipulation, and perfusion technology have allowed for mitral valve surgery to be performed using progressively smaller incisions including the minithoracotomy and hemisternotomy. Due to reports of excellent results, minimally invasive mitral valve surgery has become a standard of care at certain specialized centers worldwide. This meta-analysis quantifies the effects of minimally invasive mitral valve surgery on morbidity and mortality compared with conventional mitral surgery and demonstrates equivalent perioperative mortality (1641 patients, odds ratio (OR) 0.46, 95% confidence interval 0.15—1.42, $p = 0.18$), reduced need for reoperation for bleeding (1553 patients, OR 0.56, 95% CI 0.35—0.90, $p = 0.02$) and a trend towards shorter hospital stays (350 patients, weighted mean difference (WMD) −0.73, 95% CI −1.52 to 0.05, $p = 0.07$). These benefits were evident despite longer cardiopulmonary bypass (WMD 25.81, 95% CI 13.13—38.50, $p < 0.0001$) and cross-clamp times (WMD 20.91, 95% CI 8.79—33.04, $p = 0.0007$) in the minimally invasive group. Case-control studies show consistently less pain and faster recovery compared to those having a conventional approach. Data for minimally invasive mitral valve surgery after previous cardiac surgery are limited but consistently demonstrate reduced blood loss, fewer transfusions and faster recovery compared to reoperative sternotomy. Long-term follow-up data from multiple cohort studies are also examined revealing equivalent survival and freedom from reoperation. Thus, current clinical data suggest that minimally invasive mitral valve surgery is a safe and a durable alternative to a conventional approach and is associated with less morbidity.

Keywords: Surgical procedures; Minimally invasive; Thoracic surgery; Video-assisted; Mitral valve insufficiency

1. Introduction

Minimally invasive mitral valve surgery (MIMVS) does not refer to a single approach but rather to a collection of new techniques and operation-specific technologies. These include enhanced visualization and instrumentation systems as well as modified perfusion methods, all directed toward minimizing surgical trauma by reducing the incision size [1]. In the majority of cases, MIMVS has been performed through either a right anterior minithoracotomy or a hemisternotomy. The belief that this results in less surgical trauma, blood loss, transfusion and pain, which translates into a reduced hospital stay, faster return to normal activities, less use of rehabilitation resources, and overall healthcare savings, has driven this development. Scepticism surrounding MIMVS has focused on the potential 'trade-off' of incision size against the safety and exposure of established techniques with proven durable long-term results. Despite criticism over the last decade, various institutions have adopted MIMVS and have published favorable results as single-center observational and comparative studies. A recent meta-analysis of minimal access aortic valve replacement suggested only marginal benefits for intensive care unit stay (ICU) and hospital stay over conventional surgery, despite longer operative times [2]. As yet, no such meta-analysis is available for MIMVS despite nearly 10 years of investigational data.

Changes in surgical indications, largely due to a better understanding of the natural history of organic mitral regurgitation and the increased use of repair techniques, have increased the number of minimally symptomatic patients with degenerative disease being referred for elective repair [3,4]. For MIMVS to become accepted widely, at least equivalent, if not better, short- and long-term outcomes must be demonstrated compared with sternotomy operations. This evidence should ideally come from large, multicenter prospective randomized controlled trials (RCT) that compare minimally invasive with conventional sternotomy-based mitral surgery. However, there are only two small RCTs, one of which reports data combined with minimally invasive aortic valve replacement [5,6]. The ability to conduct an effective RCT now would be compromised severely as patients and healthcare providers have preconceived notions

* Corresponding author. Address: East Carolina Heart Institute, East Carolina University, Pitt County Memorial Hospital, 600 Moye Boulevard, Greenville, NC 27834, USA. Tel.: +1 252 744 4822; fax: +1 252 744 3051.
E-mail address: chitwoodw@ecu.edu (W.R. Chitwood Jr.).

1010-7940/$ — see front matter © 2008 European Association for Cardio-Thoracic Surgery. Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.ejcts.2008.07.057

about surgical approaches. This attitude would render patients unlikely to participate in a trial where randomization to sternotomy as a control cohort would be possible.

In the absence of large well-designed RCTs, data regarding short- and long-term outcomes are available from multiple case-control studies and observational studies. The aim of this report is to review the published randomized and nonrandomized comparative studies that compare minimally invasive endoscopic mitral valve surgery, excluding telemanipulation, to conventional approaches. Moreover, we integrate meta-analytical data to draw more useful conclusions about important short- and mid-term outcome metrics. Long-term outcomes are assessed using multiple large cohorts, to compare these to published sternotomy data.

2. Overview of the evolution of minimally invasive mitral valve surgery

In the mid-1990s, surgeons began to explore the potential advantages of minimizing incision size during cardiac surgery. Cosgrove and Cohn independently showed that mitral valve operations could be performed safely and efficiently using either parasternal or hemisternotomy incisions. Complications including slower healing, increased lung herniation, and less cosmetically appealing results led to the former being abandoned [7,8]. Carpentier performed the first video-assisted mitral valve repair through a minithoracotomy in February of 1996 [9]. Soon after, the East Carolina University group performed the first mitral valve replacement through a minithoracotomy, using video-direction, a transthoracic aortic clamp, and retrograde cardioplegia [10,11]. In 1997, we presented our first experience with 31 video-assisted mitral operations, reporting a 30-day mortality rate of 3.2% and no major complications [12]. In 1998, Mohr reported the Leipzig University experience using port-access (PA) technology, which was based on endo-aortic balloon occlusion (EABO) rather than direct aortic clamping [13].

The next major development was the introduction of a voice-controlled robotic camera arm (AESOP 3000, Computer Motion Inc., Santa Barbara. CA, USA) which allowed precise tremor-free camera movements with less lens cleaning. This technology translated into reduced cardiopulmonary bypass (CPB) and cross-clamp (XC) times [14,15], and enabled even smaller incisions with better valve and subvalvar visualization. The next evolutionary leap in endoscopic mitral surgery was the development of three-dimensional (3D) vision and computer-assisted telemanipulation that could transpose surgical movements from outside the chest wall to deep within cardiac chambers. Currently, the most widely used system is the Da Vinci® telemanipulation system (Intuitive Surgical Inc., Mountain View, CA).

3. Patients and methods

3.1. Literature search

The MEDLINE search strategy combined 'Cardiac surgical procedure' with the following MeSH terms: 'Surgical procedures, minimally invasive', 'Thoracic surgery, video-assisted', Endoscopy' AND with 'Mitral valve insufficiency', 'Mitral valve prolapse', and 'Mitral valve'. To reflect contemporary practice, the search was limited to the last 10 years and additional limits were English language citations and human subjects. The bibliographies of retrieved articles were searched for relevant articles. In addition, the 'related articles' function in PubMed was used as a further check of rigor. Where multiple cohort studies were published by a single institution, the largest or most informative study was included.

3.2. Inclusion criteria for meta-analysis

Intra-operative study variables included CPB and XC times, and postoperative ones were mortality, neurologic events (CVA), reoperation for bleeding, new atrial fibrillation (AF), intensive care unit (ICU) times, and hospital length of stay (LOS). The guidelines of the Meta-Analysis of Observational Studies in Epidemiology group were followed [16]. Both RCTs and case-control studies were used for the meta-analysis if they included at least one of the outcomes of interest. Reports presenting data for minimally invasive aortic and mitral valve surgery were only included if the mitral valve data were presented separately; studies reporting reoperative data were excluded from the meta-analysis. Studies in which data were not presented as mean and standard deviation (SD) or if this was not calculable were excluded from the analysis.

3.3. Statistical analysis

Meta-analyses were performed either using odds ratios (OR) or weighted mean differences (WMD) as the summary statistic for binary or continuous variables, respectively. The analyses were performed according to the recommendations of the Cochrane Collaboration and the Quality of Reporting of Meta-analyses guidelines [17]. An OR less than one or WMD less than one favors MIMVS over sternotomy. Random effects models were used as these assume variation between studies and are preferred for surgical data as selection criteria and risk profiles for patients differ between centers. Statistical significance was set at $p < 0.05$. Data were analysed using Review Manager version 4.2.10 (The Cochrane Collaboration, Oxford, England).

4. Results

We identified 43 published reports and of these there were two RCTs, 17 case-control studies, and 24 cohort studies. Of these studies, one RCT and ten case-control studies, published between 1998 and 2005, met the inclusion criteria (Table 1). Cohort patients numbered 2827, with 1358 in the MIMVS group and 1469 in the conventional sternotomy group. One comparative series was excluded [12] as more recent inclusive data from the same group were found [14]. One report contained data from the Society of Thoracic Surgeons (STS) database as the control arm and therefore was excluded [18]. One report presented results for mitral valve repair (MVP) and replacement (MVR) separately without presenting a combined group; the data for each were therefore analysed as independent studies [19]. The only randomized study included in the meta-analysis was by Dogan

Table 1
Studies comparing minimally invasive mitral valve surgery to sternotomy

Study, year, reference	Period	No. of patients		Valve	Approach	Design	Important findings
		MI	St				
Glower et al. (1998) [21]	N/A	21	20	MV	MT	CC	MI group had longer CPB times, better valvar/subvalvar visualization, returned to normal activity 5 weeks ahead of sternotomy patients
Asher et al. (1999) [29]	1/96–9/96	100	100	MV, AV	Not defined	CC	MI group had longer CPB/XC times, shorter hospital stay
Schneider et al. (2000) [27]	N/A	21	13	MV	MT	CC	MI group had longer CPB time, no difference in cerebral microembolic rate
Grossi et al. (2001) [20]	5/96–2/99	100	100	MV	MT	CC	Reported 1 year results: no difference in residual MR, freedom from reoperation or functional improvement between groups
Felger et al. (2001) [14]	9/96–11/00	127	100	MV	MT	CC	Robotic direction with AESOP led to ↓ blood loss, ventilation and hospital stay compared to St group, and also ↓ CPB and XC times compared to manually directed videoscope
De Vaumas et al. (2003) [26]	N/A	10	10	MV	PS, 8-10cm	CC	PS group had longer CPB/XC times, ↑blood loss
McCreath et al. (2003) [30]	3/90–10/00	214	87	MV	MT	CC	Reduced acute renal injury with MI approach
Gaudiani et al. (2004) [22]	1/97–12/02	205	616	MV	UHS, LHS, MT	CC	Shorter hospital stay for MI repair; less CVA for MI replacement.
Mihaljevic et al. (2004) [24]	7/96–4/03	474	337	MV	LHS, PS	CC	MI group were lower risk patients. Low periop mortality in both groups (0.2% vs 0.3%). 5-year survival better for MI group (95% vs 86%, $p = 0.03$)
Dogan et al. (2005) [5]	N/A	20	20	MV	MT	R	Intraoperative problem with EABO in 45%. No difference in markers of myocardial and cerebral injury, or pulmonary and neuropsychological tests between groups
Ryan et al. (2005) [19]	12/97–12/04	117	117	MV	MT	CC	MI group had longer CPB/XC times for repair, otherwise no differences
· · · · · · · · ·							
Cohn et al. (1997) [8]	7/96–4/97	50	50	MV, AV	PS, UHS	CC	MI group had longer CPB and XC times, ↓transfusion, greater patient satisfaction, less pain, faster return to normal activity, charges 20% less
Chitwood et al. (1997) [12]	5/96–3/97	31	100	MV	MT	CC	MI group had longer CPB/XC times, less transfusion, fewer re-explorations, reduced CVA, shorter ICU/hospital stays, reduced charges (↓27%) and costs (↓34%)
Reichenspurner et al. (1998) [18]	1/97–98	100	100	MV	MT	CC	Only difference was reduced AF in MI group
Grossi et al. (1999) [23]	1/94–12/98	111	259	MV, AV	MT	CC	Assessed patients ≥70 years old. MI group had lower sepsis/wound complications, less FFP, shorter hospital stay
Walther et al. (1999) [32]	10/96–5/97	129	209	MV, AV, CABG	MT, UHS	CC	MT group approach had lower pain levels from day 3 onwards due to better thoracic stability
Hamano et al. (2001) [6]	4/97–12/98	21	27	MV, AV	PS 67%, UHS 29%, LHS 4%	R	No difference in CPB/XC times, transfusion requirements or SIRS between groups
Grossi et al. (2001) [25]	5/96–10/98	109	88	MV, AV	MT	CC	MI group had similar mortality, longer CPB times, shorter hospital stay, fewer transfusions and septic complications
Yamada et al. (2003) [28]	1/99–6/01	66	50	MV AV	LHS	CC	MI group had longer CPB/XC times, less analgesics, less delirium, earlier food intake and Foley removal, and shorter ICU stay

Studies above the dotted line met the inclusion criteria for meta-analysis. AV, aortic valve; CC, case-control; CPB, cardiopulmonary bypass; CVA, cerebrovascular accident; EABO, endoaortic balloon occlusion; FFP, fresh frozen plasma; LHS, lower hemisternotomy; MI, minimally invasive; MT, minithoracotomy; MV, mitral valve; N/A, not available in text; PS, right parasternal; R, randomized; St, sternotomy; UHS, upper hemisternotomy; XC, cross-clamp.

et al. in which 20 patients in each arm were reported to have equivalent findings of ability to repair the valve, CPB and XC times, markers of myocardial and cerebral damage as well as pulmonary and neuropsychological tests [5]. Although the mean values for ventilation time, ICU time, hospital stay, and red blood cell transfusion were all lower in the MI group, these values did not reach statistical significance.

4.1. Mortality

Of the 11 comparative studies evaluating mortality, none found a significant difference between the minimally invasive and conventional approaches [12,14,18–26]. In the largest study by Mihaljevic et al. 474 minimally invasive mitral operations (mostly lower sternotomy and right parasternal) were compared with 337 median sternotomy procedures. The perioperative mortality was 0.2% for the minimally invasive group and this compared favorably with 0.3% in the sternotomy cohort. However, the MIMVS patients were found to be a lower risk group (better ejection fraction, more repairs, less symptomatic) and no attempt was made to adjust for these differences [24]. Grossi et al. matched 88 patients undergoing minimally invasive aortic and mitral valve surgery over a 2.5-year period (through either a 2nd or 4th interspace incision) to

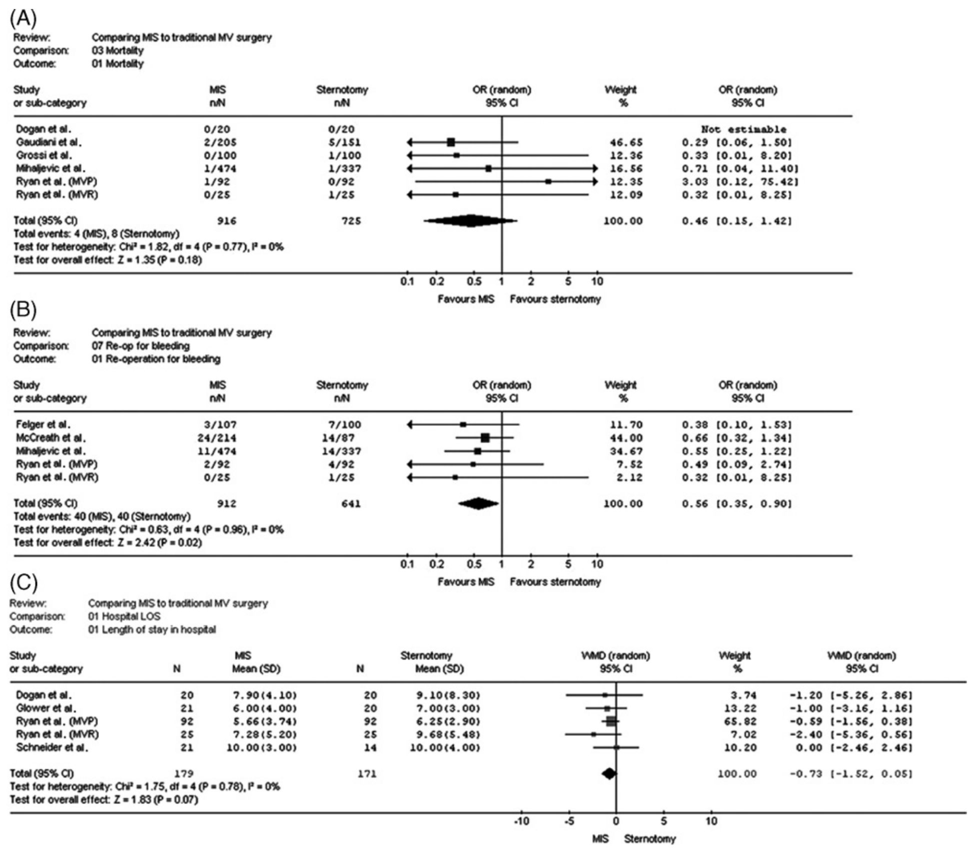

Fig. 1. Overall meta-analysis of perioperative mortality, reoperation for bleeding and hospital length of stay. The diamond represents the summary odds ratio (OR) from the pooled studies with 95% confidence intervals (CIs) and is significant ($p \leq 0.05$) if it does not touch the central vertical line. Squares for each study show point estimates of treatment effect (OR) with the size of the square representing the weight attributed to each study; horizontal bars show 95% CIs for these studies. df, degrees of freedom; MIS, minimally invasive surgery; MVP, mitral valve repair; MVR, mitral valve replacement.

patients having the same valve surgery via a sternotomy [25]. They demonstrated no significant difference in hospital mortality (3.7% vs 3.4%, respectively) between groups, even though mean CPB times were 30 min longer in the MI group. Six studies met the inclusion criteria for our meta-analysis and revealed no significant mortality difference between groups (1641 patients, OR 0.46, 95% CI 0.15—1.42, $p = 0.18$) (Fig. 1, Table 2).

4.2. Neurological events

Due to restricted access with minimally invasive cardiac operations, there continues to be concern that inadequate deairing can cause a higher incidence of neurological events. In his early series, Mohr reported an 18% incidence of postoperative confusion; however, continuous CO_2 insufflation was not used as in more recent series [13]. Ten studies reported no difference in the incidence of stroke [14,18—21,23—27], while two showed a reduced incidence with a minimally invasive approach [12,22]. There was no significant difference in neurological events on meta-analysis of six eligible studies (1801 patients, OR 0.66, 95% CI 0.23—1.93, $p = 0.45$). Schneider et al. used trans-cranial Doppler to detect cerebral microemboli in 21 MIMVS patients undergoing endoaortic balloon occlusion with continuous CO_2 chest cavity insufflation. These were compared to 14 patients undergoing conventional mitral surgery [27]. They found no significant difference in the cerebral microembolic rate between either technique.

Table 2
Meta-analysis of outcomes

Outcome	No. of patients	No. of studies	OR/WMD (95% CI)	p value	Heterogeneity, χ^2	χ^2, p value
Mortality	1641	6	0.46 (0.15 to 1.42)	0.18	1.82	0.77
Stroke	1801	6	0.66 (0.23 to 1.93)	0.45	6.77	0.24
CPB	871	8	25.81 (13.13 to 38.50)	<0.0001	27.05	0.0003
XC	671	7	20.91 (8.79 to 33.04)	0.0007	24.98	0.0003
Re-op for bleeding	1553	5	0.56 (0.35 to 0.90)	0.02	0.63	0.96
New onset AF	539	4	0.86 (0.59 to 1.27)	0.45	2.25	0.52
ICU stay	309	4	−0.36 (−0.80 to 0.08)	0.1	3.26	0.35
Hospital stay	350	5	−0.73 (−1.52 to 0.05)	0.07	1.75	0.78

AF, atrial fibrillation; CPB, cardiopulmonary bypass time; ICU, intensive care unit; XC, cross-clamp time.

4.3. Operative times

There were consistent findings that CPB and XC times were longer with a minimally invasive approach. There was evidence suggesting that parity can be achieved with experience while certain high volume centers report shorter operative times with MIMVS [24]. Of the 16 studies reporting cardiopulmonary bypass times, 10 described longer durations for MIMVS. Seven of 14 groups reported longer aortic cross-clamp times [6,8,12,14,18–30]. Meta-analysis of eligible studies showed significantly longer CPB (871 patients, WMD 25.81, 95% CI 13.13–38.50, $p < 0.0001$) and XC times (671 patients, WMD 20.91, 95% CI 8.79–33.04, $p = 0.0007$) with the minimally invasive approach.

4.4. Bleeding, transfusion and re-exploration

A reduction in postoperative hemorrhage and transfusion requirements has been suggested as a potential advantage of minimally invasive valve surgery. This benefit is important given the significant morbidity and mortality associated with transfusions and re-exploration for bleeding [31]. Four comparative studies reported blood loss volume with three utilizing a minithoracotomy [12,14,21] and one selecting a parasternal approach [26]. Few of these series met the inclusion criteria for the meta-analysis. Chitwood et al. demonstrated no difference in blood loss or blood product transfusions in 31 videoscopic mitral procedures compared with a conventional sternotomy, despite fewer re-explorations for bleeding [12]. The addition of a voice-activated robotic camera arm (AESOP 3000, Computer Motion, Inc., Galeta, CA) led to a reduction in blood loss as well as CPB and XC times. Nevertheless, there was no significant difference either in the percentage of patients receiving transfusions or the amount of blood products transfused [14]. In a consecutive series of 41 patients undergoing either port access ($n = 21$) or sternotomy ($n = 20$) mitral surgery, Glower et al. demonstrated no significant difference in chest tube drainage or transfusion requirements despite longer CPB times in the former [21].

Three of 10 studies showed reduced transfusion requirements with a minimally invasive approach, compared to conventional surgery [8,23,25] whilst the others showed no difference [6,12,14,19,21,26,32]. Too few studies met the inclusion criteria for meta-analysis (percent transfused, two studies; units transfused, three studies). In patients 70 years or older, Grossi et al. reported reduced plasma transfusions with a minimally invasive ($n = 111$) compared to a conventional ($n = 259$) approach [23]. However, the minimally invasive cohort had a lower preoperative risk profile (e.g. fewer redo operations), and there was no attempt to adjust for this baseline difference in the analysis. More convincing evidence came from a subsequent study by the same group that showed 13% fewer total transfusions with 1.8 fewer units of red blood cells using a minithoracotomy compared to a sternotomy [25]. Similar data from Cohn et al. confirm that patients undergoing minimally invasive valve surgery are transfused 1.8 units less compared to a conventional cohort [8].

Two of seven studies [12,14] demonstrated a reduced need for reoperation for bleeding with a minimally invasive approach [18,19,23,24,26]. Five studies met the inclusion criteria for the meta-analysis that showed a significant reduction in reoperation for bleeding with a MI approach (1553 patients, OR 0.56, 95% CI 0.35–0.90, $p = 0.02$).

4.5. Atrial fibrillation (AF)

It has been suggested that a less traumatic surgical approach would be a less potent trigger of postoperative AF. Five of six studies, however, demonstrated this not to be the case [12,14,18,19,21,29], and on meta-analysis of four eligible studies, there was no significant difference between minimally invasive and sternotomy approaches (539 patients, OR 0.86, 95% CI 0.59–1.27, $p = 0.45$). Asher et al. addressed this question specifically in a cohort of 100 patients having elective primary minimally invasive aortic or mitral valve surgery and compared them to a matched control group undergoing a median sternotomy [29]. They found a similar prevalence of postoperative AF using either method, even when stratified for valve type. However, the PAIR registry reported a 10% incidence of new onset atrial fibrillation with the port access technique which is lower than that expected for sternotomy [33].

4.6. Septic complications

The incidence of septic wound complications is less with thoracotomy than median sternotomy. Of the three studies of mini-thoracotomy mitral valve surgery that reported wound complications compared to median sternotomy, Grossi et al. reported an incidence of 0.9% and 5.7% for mini-thoracotomy and sternotomy cases, respectively ($p = 0.05$) [25]. This increased to 1.8% and 7.7%, respectively, in elderly patients ($p = 0.03$) [23], whereas Felger et al. reported no significant difference [14].

4.7. Pain and speed of recovery

Of all the potential benefits of MIMVS, a reduction in pain and faster return to normal activity is the most consistent finding. All four studies that measured postoperative pain levels reported less compared to sternotomy [8,21,28,32] and both studies reporting time to return to normal activities noted a significant advantage for a minimally invasive approach [8,21]. In a nonrandomized study, Walther et al. reported equivalent pain for the first two postoperative days when a minithoracotomy approach was compared to sternotomy with a subsequent significant reduction of pain in the MI group from day 3 onwards, a difference which progressively widened with time [32]. Better stability of the bony thorax led to earlier mobilization and a faster return to activities of daily living. Glower reported that postoperative pain tended to resolve more quickly with a minimally invasive approach and that these patients returned to normal activity 5 weeks more rapidly than those having a median sternotomy (4 ± 2 weeks vs 9 ± 1 weeks, $p = 0.01$) [21]. Cohn's data is concordant with less pain in hospital and after discharge, less analgesic usage, greater patient satisfaction and a return to normal activity 4.8 weeks ahead of sternotomy patients [8]. Vanermen reported that 94% of his patients report no or mild postoperative pain, 99.3% feel they have an aesthetically pleasing scar, 93% would choose the same procedure again if

Table 3
Most recent observational cohort studies of minimally invasive mitral valve surgery

Study, year, reference	Institution/City	Period	No of patients	Mortality (%)		Stroke (%)	
				MVP (%)	MVR (%)	MVP (%)	MVR (%)
Glower et al. (2000) [33]	PAIR	7/97–8/99	1059	1.6	5.5	2.6	2.8
Grossi et al. (2002) [37]	NYU	11/95–11/01	714	1.1	5.8	2.9	–
Soltesz et al. (2007) [1][a]	Brigham	7/96–2007	663	0.5	3.1	1	–
Chitwood et al. (2007)[b]	ECU	5/96–9/07	535	2.0	3.8	1.5	1.5
Casselman et al. (2003) [34]	Aalst	2/97–4/02	306	0.4	2.5	0.4	0
Cosgrove et al. (2003) [38]	Cleveland	1996–2002	1427	0.3	–	1.8	–
Walther et al. (2004) [39]	Leipzig	6/96–2004	1000	3.9	–	4.3	–
Mishra et al. (2005) [40]	New Delhi	9/97–12/04	430	0.5	–	0.5	–
Aybek et al. (2006) [41]	Frankfurt	7/97–5/04	241	3.3	–	0.8	–
Torracca et al. (2006) [42]	Milan	10/99–12/03	104	0	–	0	–

ECU, East Carolina University; MVP, mitral valve repair; MVR, mitral valve replacement; NYU, New York University; PAIR, port access international registry; STS, Society of Thoracic Surgeons.
[a] Includes data from Mihaljevic et al. [24].
[b] Unpublished data.

Table 4
Summary data derived from above cohort studies compared to data from STS Fall 2007 report

		No. of patients	No. of studies	Summary data (%)	STS data (%)
Mortality	Repair	2176	6	1.1	1.5
	Replacement	979	5	4.9	5.5
	Overall	6253	10	2.0	3.3
Stroke	Repair	1226	4	1.6	1.9
	Replacement	778	3	2.3	3.2
	Overall	6290	10	2.2	2.5

Data for repair and replacement are derived from those studies where these variables are reported independently. Overall data are derived from all studies combined.

they had to have redo surgery and 46% are back at work within 3 weeks [34]. However, perhaps the most insightful piece of evidence for patient preference of MIMVS comes from two studies reporting that those who have had a MI approach as their second procedure all felt that their recovery was more rapid and less painful than their original sternotomy [14,35].

4.8. Hospital stay, costs and discharge disposition

Does a more rapid recovery translate into a shorter stay in hospital and therefore reduced costs? Eight of 14 studies reported less time in hospital with a MI approach [8,12, 14,19,21–29,32]. Only five studies were eligible for meta-analysis and although the trend indicated this to be the case, the result was not statistically significant (350 patients, WMD −0.73, 95% CI −1.52 to 0.05, $p = 0.07$) (Fig. 1). Chitwood, Cohn and Cosgrove equated this to a 34%, 20% and 7% cost saving, respectively [8,12,36]. Moreover, these patients had fewer requirements for post-hospital rehabilitation, which is a significant advantage in terms of healthcare savings with 91% being discharged home compared to 67% with a conventional approach [8,24].

4.9. Intermediate- and long-term results

Comparing a consecutive cohort of 100 minithoracotomy mitral valve operations to the previous 100 sternotomy mitral valve procedures, Grossi et al. found comparable 1-year freedom from reoperation (96.8% vs 94.4%, $p = 0.38$, respectively) with similar net improvement in functional class [20]. Mihaljevic et al. reported significantly better actuarial survival at 5 years for minimally invasive compared to sternotomy patients (95% vs 86%), but this may be explained by a lower risk profile [24]. Many of the cohort studies are temporally updated results from a few select high-volume centers such as the Cleveland Clinic, the Brigham and Women's Hospital, New York University, University of Leipzig, OLV Clinic (Aalst, Belgium) and East Carolina University. Therefore, only the most recent data from 10 cohorts with 6479 patients are considered, herein

Table 5
Studies reporting long-term results of minimally invasive mitral valve surgery

Study, year, reference	Institution	Survival	Freedom from re-operation
Gulielmos et al. (2000) [43]	Dresden	93.5% at 3.3 years	–
Casselman et al. (2003) [34]	Aalst	95.4 ± 1.7% at 4 years	91 ± 3.5% at 4 years
Greelish et al. (2003) [44]	Brigham	95% at 5 years	92% at 5 years
Walther et al. (2004) [39]	Leipzig	83% at 6.8 years	–
Mishra et al. (2005) [40]	New Delhi	99% at 3.2 years	99.3% at 3.2 years
Aybek et al. (2006) [41]	Frankfurt	90.7% at 6.3 years	96.2% at 6.3 years
Torracca et al. (2006) [42]	Milan	100% at 2.3 years	95.2% at 4 years

(Table 3) [1,33,34,37–42]. The crude unadjusted mortality rates for the entire cohort are 1.1% for mitral valve repair and 4.9% for mitral valve replacement. The corresponding data from the Society of Thoracic Surgeons (STS) Fall 2007 report are 1.5% for MVP and 5.5% for MVR (Table 4). The neurological event rates for the entire cohort are lower than STS data. With regard to long-term survival, we found seven studies reporting from 100% survival at a mean of 2.3 years to 83% at 6.8 years postoperatively (Table 5) [34,39–44]. This compares favorably to 5-year survivals of 86.4% reported by the Mayo Clinic [45] and 82% reported by the Cleveland Clinic [46]. Five studies reported freedom from reoperation ranging from 99.3% at 3.2 years to 91% at 4 years [34,40–42,44]. The longest follow-up was 6.3 years with 96.2% freedom from reoperation. Again this compares favorably to the Mayo Clinic data which indicates a risk of reoperation of between 0.5% per year for isolated posterior leaflet prolapse to 1.64% per year for isolated anterior leaflet prolapse [45].

5. Special situations

5.1. Reoperative surgery

The greatest potential benefit of a right mini-thoracotomy is the avoidance of sternal re-entry and limited dissection of adhesions, avoiding the risk of injury to cardiac structures or patent grafts, and limiting the amount of postoperative bleeding [47]. This consistently translates into reduced blood loss, less transfusions and faster recovery. There are seven important studies (three case-control and four cohort) describing a right minithoracotomy approach for reoperative valve surgery [35,48–53] and one describing a left posterior approach [54] (Table 6).

The case-control studies all demonstrated superiority of the right mini-thoracotomy versus a reoperative sternotomy. The largest series from Sharony et al. demonstrated equal mortality (5% for isolated mitral operations), fewer wound infections, less blood product utilization, decreased hospital length of stay, and slightly more favorable mid-term outcomes with a mini-thoracotomy approach for reoperative mitral and aortic valve surgery [48]. In 71 reoperative mitral valve operations of which 38 were done through a minithoracotomy, Bolotin et al. noted no difference in mortality or CPB times but significantly reduced intubation times, blood transfusion and hospital stay with a minimally invasive approach [49]. In a retrospective study from Duke University, patients undergoing a right mini-thoracotomy for redo mitral surgery had lower mortality, less blood loss and fewer transfusions than via a redo sternotomy or an antero-lateral thoracotomy [50].

Vanermen recently reported 80 adults undergoing endoscopic MV and TV reoperative surgery with an operative mortality of 3.8% [51]. There was one intra-operative and two postoperative strokes. Survival at 1 and 4 years was $93.6 \pm 2.8\%$ and $85.6 \pm 6.4\%$ respectively, and there was one late reoperation at five years. At the University of Michigan, Bolling et al. used a 5–10 cm right anterior 5th interspace thoracotomy in 22 patients for reoperative mitral and tricuspid valve surgery with no 30-day mortality [35]. Patients were weaned from ventilation at a mean of 5 h and received 1.3 ± 1 units of blood. There were no re-explorations for bleeding. The important message from this study was that all patients interviewed considered that their recovery was more rapid and less painful than their original sternotomy.

Onnasch et al. reported 39 patients undergoing redo mitral valve surgery through a right minithoracotomy with a mortality of 5.1% [53]. One patient experienced transient hemiplegia due to migration of the aortic balloon endoclamp. This group concluded that a MI approach offers excellent exposure and minimizes the need for mediastinal dissection and optimizes patient comfort. Their updated series described 97 patients undergoing mitral reoperations since 1996 with an in-hospital mortality of 5.6% [52].

Finally, the New York University group have described a left posterior minithoracotomy approach in 40 patients in whom a right thoracotomy was precluded, e.g. right mastectomy/irradiation [54]. They concluded this approach to be a valuable option in complicated reoperative mitral

Table 6
Studies reporting a minithoracotomy approach for reoperative mitral valve surgery

Study, reference	Period	No. of patients		Valve	Design	Important findings
		MI	Conv			
Sharony et al. (2006) [48]	1995–2002	161	St 337	AV, MV	CC	Surgical approach *not* an independent risk factor for mortality. However, fewer wound infections, less blood product transfusion and shorter hospital stays for MI group
Bolotin et al. (2004) [49]	1/96–6/03	38	St 33	MV	CC	Shorter intubation and LOS, reduced blood transfusion
Burfeind et al. (2002) [50]	1985–2001	60	Th 37 St 155	MV ± TV	CC	Less bleeding, transfusion and mortality with minithoracotomy approach
Casselman et al. (2007) [51]	12/97–5/06	80	–	MV, TV	Cohort	Observed/expected mortality, 0.24. Four-year survival $85.6 \pm 6.4\%$. One reoperation at 5 years. 99% of patients preferred MI approach to prior sternotomy
Vlessis et al. (1998) [35]	12/96–10/97	22	–	MV ± TV or ASD	Cohort	No mortality, mean ventilatory support 5 h, mean blood transfusion 1.3 ± 1.0 units, mean LOS 5.9 days. All felt less pain and faster recovery than prior sternotomy
Walther et al. (2006) [52] [a]	3/97–1996	97		MV	Cohort	Mortality 7.2% compared to registry data of 8.75%. Repair in 56%

ASD, atrial septal defect; AV, aortic valve; CC, case-control; Conv, conventional; LOS, length of stay; MI, minimally invasive; MV, mitral valve; St, sternotomy; Th, standard anterolateral right thoracotomy; TV, tricuspid valve.

[a] Updated results from a previous study [53].

procedures with acceptable perioperative morbidity and mortality.

5.2. Low ejection fraction

Previously considered by many as a contraindication to a minimally invasive approach, Mohr has treated 68 patients having a dilated cardiomyopathy (EF 21 $\pm$ 8%) with MI mitral valve repair and 11 with a replacement with an overall 8.8% mortality [52]. Severe pulmonary hypertension was present in 45.6%. Postoperatively, 6.3% developed renal failure and 7.9% had low cardiac output. Despite successful mitral valve repair, seven patients required transplantation during follow-up.

5.3. Elderly patients

Two studies have looked at the application of MI techniques specifically to elderly patients. Grossi et al. reviewed 111 patients undergoing MI valve surgery who were at least 70 years old and compared these to 259 patients having a sternotomy [23]. The MI group had a significantly lower incidence of sepsis and wound complications, required less frozen plasma transfusions, and had a shorter length of hospital stay. They concluded that this approach can be used safely in operations on the elderly population with excellent results. Also, Tabata et al. recently reported 123 cases of MI mitral valve repair in patients aged 70 years and older with 1.6% operative mortality as well as 5-year actuarial survival of 87% and 5-year freedom from reoperation of 93% [55].

6. Endo-aortic balloon occlusion versus transthoracic clamping

One of the most significant risks of endo-aortic balloon occlusion (EABO) is aortic dissection, and as a consequence, many surgeons have abandoned this technique. In the first PAIR report, the incidence of aortic dissection was 1.3% in the first half of the study compared to 0.2% in the second half, a difference attributable to experience, better techniques, and improved technology [56]. In comparison to transthoracic clamping (TTC), EABO is more expensive, and the clamp position is less stable. Proximal balloon dislodgement can cause innominate artery occlusion with neurological injury. Monitoring by transesophageal echocardiography and transcranial Doppler should be done routinely [57,58]. Balloon prolapse into the left ventricle can lead to inferior myocardial protection, ventricular distension or aortic valve injury.

There are three pertinent studies, all non-randomized consecutive series from Germany, demonstrating superiority of TTC over EABO. Onnasch et al. demonstrated a significantly higher risk of neurological complications with EABO (8.1% vs 1.8%, $p < 0.05$) and higher mortality (5.2% vs 3.1%, respectively). Mohr subsequently abandoned EABO for primary mitral valve procedures [59]. In 58 patients, Aybek et al. demonstrated similar results with faster operations, fewer technical difficulties, less blood loss and lower costs using the transthoracic clamp [60]. Reichenspurner et al. confirmed shorter operative times with TTC in 120 patients and with fewer complications (reduced bleeding, wound problems and fewer femoral artery reconstructions) and he showed a reduction in costs of disposables by $2800 [61].

7. Limitations of a minimally invasive approach

Clearly, there is a learning curve for the surgeon as well as the anesthetists, perfusionists and nursing teams. Mohr reported a high mortality (9.8%) in his early port access cases, partially procedure-related with two of 51 patients suffering an aortic dissection [13]. After simplification of the surgical procedure the mortality decreased to 3%. Vanermen demonstrated that ICU and hospital stays decrease with increasing experience [62].

There are potential vascular risks with femoral cannulation, especially with the larger port access femoral cannula. Groin seromas can be problematic but are kept to a minimum by dissection only of the anterior surface of the vessels as well as clipping lymphatics. When the pericardium is opened too posteriorly, phrenic nerve palsy has been reported and can be avoided by placing the pericardiotomy at least 3 cm anterior to it. Excess tension by pericardial retraction sutures should be avoided. Although some have suggested that a small anterior thoracotomy is associated with equal or greater postoperative pain [63,64], there is good evidence as detailed above that it actually reduces postoperative discomfort and enhances recovery [21,25,65].

8. Conclusions

Over the last decade there has been a transformation in the way cardiac surgeons, cardiologists and patients decide the approach to cardiac therapies. Less invasive procedures are demanded but at the same time proven safety, efficacy and durability are expected. There is no prior level one evidence to justify switching to minimally invasive mitral valve surgery. All the reviewed evidence demonstrates that minimally invasive mitral valve surgery is associated with equal mortality and neurological events despite longer cardiopulmonary bypass and aortic cross-clamp times. However, there is less morbidity in terms of reduced need for reoperation for bleeding, a trend towards shorter hospital stay, less pain and faster return to preoperative function levels than conventional sternotomy-based surgery. This would be expected to translate into improved utilization of limited healthcare resources. With follow-up now of almost 7 years it is clear that long-term outcomes are equivalent to those of conventional surgery. Data for minimally invasive mitral valve surgery after previous cardiac surgery is limited but consistently demonstrates reduced blood loss, fewer transfusions and faster recovery compared to reoperative sternotomy. Almost all patients who undergo a minimally invasive mitral valve operation as their second procedure feel their recovery is more rapid and less painful than their original sternotomy.

As for the future, minimally invasive cardiac surgery is likely to become more widely adopted as growth in this niche market and cardiac surgery as a whole is often patient-driven, much in the same way that percutaneous intervention for multivessel disease has been. That is, patients do not want a sternotomy and it is important as a surgical community that we realize this. However, despite enthusiasm, caution cannot be overemphasized as traditional cardiac operations still enjoy proven long-term success and ever-decreasing morbidity and mortality and remain our measure for comparison.

References

[1] Soltesz EG, Cohn LH. Minimally invasive valve surgery. Cardiol Rev 2007;15(May–June (3)):109–15.
[2] Murtuza B, Pepper JR, Stanbridge RD, Jones C, Rao C, Darzi A, Athanasiou T. Minimal access aortic valve replacement: is it worth it? Ann Thorac Surg 2008;85(March (3)):1121–31.
[3] Enriquez-Sarano M, Avierinos JF, Messika-Zeitoun D, Detaint D, Capps M, Nkomo V, Scott C, Schaff HV, Tajik AJ. Quantitative determinants of the outcome of asymptomatic mitral regurgitation. N Engl J Med 2005;352(March 9):875–83.
[4] Tribouilloy CM, Enriquez-Sarano M, Schaff HV, Orszulak TA, Bailey KR, Tajik AJ, Frye RL. Impact of preoperative symptoms on survival after surgical correction of organic mitral regurgitation: rationale for optimizing surgical indications. Circulation 1999;99(January (3)):400–5.
[5] Dogan S, Aybek T, Risteski PS, Detho F, Rapp A, Wimmer-Greinecker G, Moritz A. Minimally invasive port access versus conventional mitral valve surgery: prospective randomized study. Ann Thorac Surg 2005;79(February (2)):492–8.
[6] Hamano K, Kawamura T, Gohra H, Katoh T, Fujimura Y, Zempo N, Miyamoto M, Tsuboi H, Tanimoto Y, Esato K. Stress caused by minimally invasive cardiac surgery versus conventional cardiac surgery: incidence of systemic inflammatory response syndrome. World J Surg 2001;25(February (2)):117–21.
[7] Navia JL, Cosgrove 3rd DM. Minimally invasive mitral valve operations. Ann Thorac Surg 1996;62(November (5)):1542–4.
[8] Cohn LH, Adams DH, Couper GS, Bichell DP, Rosborough DM, Sears SP, Aranki SF. Minimally invasive cardiac valve surgery improves patient satisfaction while reducing costs of cardiac valve replacement and repair. Ann Surg 1997;226(October (4)):421–6. discussion 7–8.
[9] Carpentier A, Loulmet D, Carpentier A, Le Bret E, Haugades B, Dassier P, Guibourt P. [Open heart operation under videosurgery and minithoracotomy. First case (mitral valvuloplasty) operated with success]. Comptes rendus de l'Academie des sciences 1996;319(March (3)):219–23.
[10] Chitwood Jr WR, Elbeery JR, Chapman WH, Moran JM, Lust RL, Wooden WA, Deaton DH. Video-assisted minimally invasive mitral valve surgery: the "micro-mitral" operation. J Thorac Cardiovasc Surg 1997;113(February (2)):413–4.
[11] Chitwood Jr WR, Elbeery JR, Moran JF. Minimally invasive mitral valve repair using transthoracic aortic occlusion. Ann Thorac Surg 1997;63(May (5)):1477–9.
[12] Chitwood Jr WR, Wixon CL, Elbeery JR, Moran JF, Chapman WH, Lust RM. Video-assisted minimally invasive mitral valve surgery. J Thorac Cardiovasc Surg 1997;114(November (5)):773–80. discussion 80–2.
[13] Mohr FW, Falk V, Diegeler A, Walther T, van Son JA, Autschbach R. Minimally invasive port-access mitral valve surgery. J Thorac Cardiovasc Surg 1998;115(March (3)):567–74. discussion 74–6.
[14] Felger JE, Chitwood Jr WR, Nifong LW, Holbert D. Evolution of mitral valve surgery: toward a totally endoscopic approach. Ann Thorac Surg 2001;72(October (4)):1203–8. discussion 8–9.
[15] Falk V, Walther T, Autschbach R, Diegeler A, Battellini R, Mohr FW. Robot-assisted minimally invasive solo mitral valve operation. J Thorac Cardiovasc Surg 1998;115(February (2)):470–1.
[16] Stroup DF, Berlin JA, Morton SC, Olkin I, Williamson GD, Rennie D, Moher D, Becker BJ, Sipe TA, Thacker SB. Meta-analysis of observational studies in epidemiology: a proposal for reporting. Meta-analysis of Observational Studies in Epidemiology (MOOSE) group. JAMA 2000;283(April (15)):2008–12.
[17] Moher D, Cook DJ, Eastwood S, Olkin I, Rennie D, Stroup DF. Improving the quality of reports of meta-analyses of randomised controlled trials: the QUOROM statement. Quality of Reporting of Meta-analyses. Lancet 1999;354(November (9193)):1896–900.
[18] Reichenspurner H, Welz A, Gulielmos V, Boehm D, Reichart B. Port-access cardiac surgery using endovascular cardiopulmonary bypass: theory, practice, and results. J Card Surg 1998;13(July (4)):275–80.
[19] Ryan WH, Dewey TM, Mack MJ, Herbert MA, Prince SL. Mitral valve surgery using the classical 'heartport' technique. J Heart Valve Dis 2005;14(November (6)):709–14. discussion 14.
[20] Grossi EA, LaPietra A, Ribakove GH, Delianides J, Esposito R, Culliford AT, Derivaux CC, Applebaum RM, Kronzon I, Steinberg BM, Baumann FG, Galloway AC, Colvin SB. Minimally invasive versus sternotomy approaches for mitral reconstruction: comparison of intermediate-term results. J Thorac Cardiovasc Surg 2001;121(April (4)):708–13.
[21] Glower DD, Landolfo KP, Clements F, Debruijn NP, Stafford-Smith M, Smith PK, Duhaylongsod F. Mitral valve operation via port-access versus median sternotomy. Eur J Cardiothorac Surg 1998;14(October (Suppl. 1)):S143–7.
[22] Gaudiani VA, Grunkemeier GL, Castro LJ, Fisher AL, Wu Y. Mitral valve operations through standard and smaller incisions. Heart Surg Forum 2004;7(4):E337–42.
[23] Grossi EA, Galloway AC, Ribakove GH, Buttenheim PM, Esposito R, Baumann FG, Colvin SB. Minimally invasive port access surgery reduces operative morbidity for valve replacement in the elderly. Heart Surg Forum 1999;2(3):212–5.
[24] Mihaljevic T, Cohn LH, Unic D, Aranki SF, Couper GS, Byrne JG. One thousand minimally invasive valve operations: early and late results. Ann Surg 2004;240(September (3)):529–34. discussion 34.
[25] Grossi EA, Galloway AC, Ribakove GH, Zakow PK, Derivaux CC, Baumann FG, Schwesinger D, Colvin SB. Impact of minimally invasive valvular heart surgery: a case-control study. Ann Thorac Surg 2001;71(March (3)):807–10.
[26] de Vaumas C, Philip I, Daccache G, Depoix JP, Lecharny JB, Enguerand D, Desmonts JM. Comparison of minithoracotomy and conventional sternotomy approaches for valve surgery. J Cardiothorac Vasc Anesth 2003;17(June (3)):325–8.
[27] Schneider F, Onnasch JF, Falk V, Walther T, Autschbach R, Mohr FW. Cerebral microemboli during minimally invasive and conventional mitral valve operations. Ann Thorac Surg 2000;70(September (3)):1094–7.
[28] Yamada T, Ochiai R, Takeda J, Shin H, Yozu R. Comparison of early postoperative quality of life in minimally invasive versus conventional valve surgery. J Anesth 2003;17(3):171–6.
[29] Asher CR, DiMengo JM, Arheart KL, Weber MM, Grimm RA, Blackstone EH, Cosgrove 3rd DM, Chung MK. Atrial fibrillation early postoperatively following minimally invasive cardiac valvular surgery. Am J Cardiol 1999;84(September (6)):744–7. A9.
[30] McCreath BJ, Swaminathan M, Booth JV, Phillips-Bute B, Chew ST, Glower DD, Stafford-Smith M. Mitral valve surgery and acute renal injury: port access versus median sternotomy. Ann Thorac Surg 2003;75(March (3)):812–9.
[31] Murphy GJ, Reeves BC, Rogers CA, Rizvi SI, Culliford L, Angelini GD. Increased mortality, postoperative morbidity, and cost after red blood cell transfusion in patients having cardiac surgery. Circulation 2007;116(November (22)):2544–52.
[32] Walther T, Falk V, Metz S, Diegeler A, Battellini R, Autschbach R, Mohr FW. Pain and quality of life after minimally invasive versus conventional cardiac surgery. Ann Thorac Surg 1999;67(June (6)):1643–7.
[33] Glower DD, Siegel LC, Frischmeyer KJ, Galloway AC, Ribakove GH, Grossi EA, Robinson NB, Ryan WH, Colvin SB. Predictors of outcome in a multicenter port-access valve registry. Ann Thorac Surg 2000;70(September (3)):1054–9.
[34] Casselman FP, Van Slycke S, Wellens F, De Geest R, Degrieck I, Van Praet F, Vermeulen Y, Vanermen H. Mitral valve surgery can now routinely be performed endoscopically. Circulation 2003;108(September (Suppl. 1)):II48–54.
[35] Vleissis AA, Bolling SF. Mini-reoperative mitral valve surgery. J Cardiac Surg 1998;13(November–December (6)):468–70.
[36] Cosgrove 3rd DM, Sabik JF, Navia JL. Minimally invasive valve operations. Ann Thorac Surg 1998;65(June (6)):1535–8. discussion 8–9.
[37] Grossi EA, Galloway AC, LaPietra A, Ribakove GH, Ursomanno P, Delianides J, Culliford AT, Bizekis C, Esposito RA, Baumann FG, Kanchuger MS, Colvin SB. Minimally invasive mitral valve surgery: a 6-year experience with 714 patients. Ann Thorac Surg 2002;74(September (3)):660–3. discussion 3–4.
[38] Chitwood WR, Nifong LW. Minimally invasive and robotic valve surgery. In: Cohn LH, Edmunds LH, editors. Cardiac surgery in the adult. 2nd ed., New York: McGraw Hill; 2003. p. 1075–92.
[39] Walther T, Falk V, Mohr FW. Minimally invasive mitral valve surgery. J Cardiovasc Surg 2004;45(October (5)):487–95.
[40] Mishra YK, Khanna SN, Wasir H, Sharma KK, Mehta Y, Trehan N. Port-access approach for cardiac surgical procedures: our experience in 776 patients. Ind Heart J 2005;57(November–December (6)):688–93.

[41] Aybek T, Dogan S, Risteski PS, Zierer A, Wittlinger T, Wimmer-Greinecker G, Moritz A. Two hundred forty minimally invasive mitral operations through right minithoracotomy. Ann Thorac Surg 2006;81(May (5)):1618—24.
[42] Torracca L, Lapenna E, De Bonis M, Kassem S, La Canna G, Crescenzi G, Castiglioni A, Grimaldi A, Alfieri O. Minimally invasive mitral valve repair as a routine approach in selected patients. J Cardiovasc Med (Hagerstown Md) 2006;7(January (1)):57—60.
[43] Gulielmos V, Tugtekin SM, Kappert U, Cichon R, Matschke K, Karbalai P, Schueler S. Three-year follow-up after port-access mitral valve surgery. J Card Surg 2000;15(January—February (1)):43—50.
[44] Greelish JP, Cohn LH, Leacche M, Mitchell M, Karavas A, Fox J, Byrne JG, Aranki SF, Couper GS. Minimally invasive mitral valve repair suggests earlier operations for mitral valve disease. J Thorac Cardiovasc Surg 2003;126(August (2)):365—71. discussion 71—3.
[45] Suri RM, Schaff HV, Dearani JA, Sundt 3rd TM, Daly RC, Mullany CJ, Enriquez-Sarano M, Orszulak TA. Survival advantage and improved durability of mitral repair for leaflet prolapse subsets in the current era. Ann Thorac Surg 2006;82(September (3)):819—26.
[46] Gillinov AM, Blackstone EH, Rajeswaran J, Mawad M, McCarthy PM, Sabik 3rd JF, Shiota T, Lytle BW, Cosgrove DM. Ischemic versus degenerative mitral regurgitation: does etiology affect survival? Ann Thorac Surg 2005;80(September (3)):811—9. discussion 9.
[47] Byrne JG, Karavas AN, Adams DH, Aklog L, Aranki SF, Filsoufi F, Cohn LH. The preferred approach for mitral valve surgery after CABG: right thoracotomy, hypothermia and avoidance of LIMA-LAD graft. J Heart Valve Dis 2001;10(September (5)):584—90.
[48] Sharony R, Grossi EA, Saunders PC, Schwartz CF, Ursomanno P, Ribakove GH, Galloway AC, Colvin SB. Minimally invasive reoperative isolated valve surgery: early and mid-term results. J Card Surg 2006 May-Jun;21(3): 240—4.
[49] Bolotin G, Kypson AP, Reade CC, Chu VF, Freund Jr WL, Nifong LW, Chitwood Jr WR. Should a video-assisted mini-thoracotomy be the approach of choice for reoperative mitral valve surgery? J Heart Valve Dis 2004;13(March (2)):155—8. discussion 8.
[50] Burfeind WR, Glower DD, Davis RD, Landolfo KP, Lowe JE, Wolfe WG. Mitral surgery after prior cardiac operation: port-access versus sternotomy or thoracotomy. Ann Thorac Surg 2002;74(October (4)): S1323—5.
[51] Casselman FP, La Meir M, Jeanmart H, Mazzarro E, Coddens J, Van Praet F, Wellens F, Vermeulen Y, Vanermen H. Endoscopic mitral and tricuspid valve surgery after previous cardiac surgery. Circulation 2007;116(September (11 Suppl.)):I270—5.
[52] Walther T, Falk V, Mohr FW. Minimally invasive surgery for valve disease. Curr Prob Cardiol 2006;31(June (6)):399—437.
[53] Onnasch JF, Schneider F, Falk V, Walther T, Gummert J, Mohr FW. Minimally invasive approach for redo mitral valve surgery: a true benefit for the patient. J Card Surg 2002;17(January—February (1)):14—9.
[54] Saunders PC, Grossi EA, Sharony R, Schwartz CF, Ribakove GH, Culliford AT, Delianides J, Baumann FG, Galloway AC, Colvin SB. Minimally invasive technology for mitral valve surgery via left thoracotomy: experience with forty cases. J Thorac Cardiovasc Surg 2004;127(April (4)):1026—31. discussion 31—2.
[55] Tabata M, Cohn LH. Minimally invasive mitral valve repair with and without robotic technology in the elderly. Am J Geriatr Cardiol 2006;15(September—October (5)):306—10.
[56] Galloway AC, Shemin RJ, Glower DD, Boyer Jr JH, Groh MA, Kuntz RE, Burdon TA, Ribakove GH, Reitz BA, Colvin SB. First report of the Port Access International Registry. Ann Thorac Surg 1999;67(January (1)):51—6. discussion 7—8.
[57] Schneider F, Falk V, Walther T, Mohr FW. Control of endoaortic clamp position during Port-Access mitral valve operations using transcranial Doppler echography. Ann Thorac Surg 1998;65(May (5)):1481—2.
[58] Mohr FW, Onnasch JF, Falk V, Walther T, Diegeler A, Krakor R, Schneider F, Autschbach R. The evolution of minimally invasive valve surgery-2 year experience. Eur J Cardiothorac Surg 1999;15(March (3)):233—8. discussion 8—9.
[59] Onnasch JF, Schneider F, Falk V, Mierzwa M, Bucerius J, Mohr FW. Five years of less invasive mitral valve surgery: from experimental to routine approach. Heart Surg Forum 2002;5(2):132—5.
[60] Aybek T, Dogan S, Wimmer-Greinecker G, Westphal K, Mortiz A. The micro-mitral operation comparing the port-access technique and the transthoracic clamp technique. J Card Surg 2000;15(January—February (1)):76—81.
[61] Reichenspurner H, Detter C, Deuse T, Boehm DH, Treede H, Reichart B. Video and robotic-assisted minimally invasive mitral valve surgery: a comparison of the port-access and transthoracic clamp techniques. Ann Thorac Surg 2005;79(February (2)):485—90. discussion 90—1.
[62] Vanermen H, Farhat F, Wellens F, De Geest R, Degrieck I, Van Praet F, Vermeulen Y. Minimally invasive video-assisted mitral valve surgery: from port-access towards a totally endoscopic procedure. J Card Surg 2000;15(January—February (1)):51—60.
[63] Loulmet DF, Carpentier A, Cho PW, Berrebi A, d'Attellis N, Austin CB, Couetil JP, Lajos P. Less invasive techniques for mitral valve surgery. J Thorac Cardiovasc Surg 1998;115(April (4)):772—9.
[64] Chaney MA, Morales M, Bakhos M. Severe incisional pain and long thoracic nerve injury after port-access minimally invasive mitral valve surgery. Anesth Analg 2000;91(August (2)):288—90.
[65] Grossi EA, Zakow PK, Ribakove G, Kallenbach K, Ursomanno P, Gradek CE, Baumann FG, Colvin SB, Galloway AC. Comparison of post-operative pain, stress response, and quality of life in port access vs. standard sternotomy coronary bypass patients. Eur J Cardiothorac Surg 1999;16(November (Suppl. 2)):S39—42.