Minimally invasive atrioventricular valve surgery – current status and future perspectives

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ABSTRACT

We are currently witnessing rapid evolution in minimally invasive and catheter-based atrioventricular valve interventions as acceptable alternatives to classic sternotomy access (CSA). Collectively, minimally invasive atrioventricular valve surgery (MIAS) is associated with significant learning curves and its routine application is met with varying degrees of enthusiasm in view of strict quality control, clinical governance and outcome reporting. Whether the reported potential benefits and comparable efficacy across a range of long-term outcome measures reported by experienced MIAS centres can be translated into general international surgical practice, are not well defined. This paper describes the historic evolution of MIAS, the contemporary clinical outcomes of MIAS compared with CSA, and the application of MIAS in "real-life" general practice.

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INTRODUCTION

We are currently witnessing rapid evolution in the development, marketing and utilisation of robotic,[1-3] endoscopic[4-5] and trans-catheter[6-9] atrioventricular valve (AVV) repair and replacement technology as alternatives to classic sternotomy access (CSA). Collectively, minimally invasive atrioventricular valve surgery (MIAS) is associated with significant learning curves,[10] which in the context of increasing patient age, operative risk profiles, expectations and strict quality control,[11-13] potentially deter upcoming centres from incorporating MIAS programmes that utilise videoscopic or robotic vision, modified instruments, perfusion and myocardial protective strategies into clinical practice. As a result, CSA is still considered by many as the standard approach for AVV disease, and subsequent reports have emerged that challenge the historically documented potential benefits associated with MIAS.[14] In addition, sceptics may prefer interventionist driven trans-catheter intervention (TCI) programmes to avoid the transitional challenges associated with establishing MIAS programmes.[15] Various experienced MIAS centres reported their routine use of MIAS for all isolated AVV pathology with excellent long-term results,[16-17] but whether their clinical outcomes can indeed be translated into general international surgical practice are not well defined.[18-20] This paper describes the historic evolution of MIAS, the contemporary clinical outcomes of MIAS compared with CSA, and the application of MIAS in "real-life" general practice.

REVIEW CRITERIA

Contemporary, peer reviewed reports on minimally invasive mitral and tricuspid valve surgery were selected and reviewed for intra-operative, in-hospital, post-discharge and health economic outcomes and references.

THE HISTORICAL EVOLUTION OF MIAS

In the British Medical Journal of 1898, Daniel Samways became the first physician to propose that rheumatic mitral valve (MV) stenosis be treated by surgical intervention. Sir Lauder Brunton subsequently developed and reported his animal model of trans-ventricular mitral commisurotomy in 1902,[21] which was clinically applied as the first successful AVV surgical operation by Elliot Carr Cutler and Samuel Levine in 1923.[22] The 12-year-old patient survived for 4 years before passing away of pneumonia, but the poor outcomes of the subsequent 7 patients resulted in a procedural moratorium in 1929.[23]

The introduction of cardiopulmonary bypass in 1956 enabled safe intra-cardiac AVV access, with Duboist and Guiraun introducing the concepts of a trans-septal bi-atrial[24] and right atrial approaches[25] respectively. The visionary repair concepts of

MV regurgitation were proposed and refined by Davila,[26] Nichols,[27] Kay,[28] Carpentier,[29] McGoon[30] and many others.[31]

Navia and Gosgrove[32] were the first to report the concept and outcomes of a non-sternotomy, parasternal MV approach in 25 patients in 1996. There were no hospital deaths, reoperations for bleeding, embolic complications or wound infection. Cohn and his group also described their similar findings with this approach in 43 patients.[33]

The reported success of laparoscopy in general surgery resulted in the application and development of video assisted thoracic surgery, which provided Alain Carpentier and his team with the opportunity to perform the first video-assisted, right mini-thoracotomy MV-repair using ventricular fibrillation in 1996,[34] which subsequently provided the platform for various centres to refine and further develop MIAS.

Port Access™ surgery (PAS), which consists of peripheral cardiopulmonary bypass (CPB), guidewire directed anterograde endo-aortic balloon occlusion (EABO), venting, cardioplegia delivery and videoscopic guidance of routine AVV procedures through a 4cm right antero-lateral working, was initially developed by Heartport, Inc. (Redwood City, CA, USA) in 1994, and was introduced by Stevens and colleagues as a surgical method for performing bypass grafting.[35]

The teams of Frederick Mohr,[36] Hugo Vanermen[37-38] and others[39-40] refined and incorporated PAS techniques into their routine MIAS clinical practice and reported the significant potential benefits in their extensive series. As an alternative to EABO, direct aortic clamping (DAC) was introduced by Angouras and Michler[41] and further developed by Chitwood.[42-44]

Recent developments in MIAS access include the introduction of a right vertical infra-axillary thoracotomy[45] and a peri-arealor incision approach[46] – with excellent results.

Carpentier performed the first completely robotic MV procedure using the Da Vinci Surgical System (Intuitive Surgical, Inc. Sunnyvale, California, USA),[46] with various international groups now performing robotic AVV surgery as a routine with excellent reported outcomes.[47-48]

CONTEMPORARY CLINICAL OUTCOMES OF MIAS COMPARED WITH CSA

Cardiopulmonary bypass, ischaemic and procedure times

The pathophysiological and inflammatory effects of CPB and cardioplegic arrest for CSA and MIAS are well described.[49] Various reports suggest that MIAS is associated with up to 15% longer CPB , ischaemic and procedure times compared to CSA for both simple and complex AVV surgical procedures.[50-61] The transition to using single shaft instruments through limited working space and other technical factors are reported as possible contributing factors in the early experience.[62-63]

Success of complex repair and replacement procedures

The group from Aalst reported their MIAS series of 2 872 patients,[64] of which 2 183 (76.0%), 54 (1.9%) and 635 (22.1%) underwent isolated MV, isolated TV and combined MV and TV procedures. MV-repair was achieved in 96.4% (n=1822 of 1891) of primary annular dilatation and degenerative valves and constituted 81.7% (n=2866) of all MIAS procedures (n=3507). Other groups also reported excellent MIAS repair results for simple and complex AVV procedures,[17] which can also be achieved in the early learning curve.[62-63] Various reports suggest no significant difference in the success of simple or complex AVV procedures whether performed by MIAS or CSA.[57,65]

Vascular complications

Most MIAS reports utilise peripheral retrograde CPB and obtain safe cardioplegic arrest by either EBAO or DAC.[46] For PAS, the group from Aalst reported an incidence of 0.4% for aortic dissection, of which the majority occurred during the initial learning curve.[64] Compared with CSA, various conflicting reports suggest that MIAS is associated with increased central aortic or major vascular injury risk.[57,59-61] However, refinements in pre-operative aorto-iliac-axis evaluation strategies, cardiopulmonary bypass techniques,[66-67] the acquisition of guidewire skills and the application of TEE guided cannulation and EABO placement techniques[68] significantly decrease the risks of vascular injuries.[69] In addition, it appears that EABO is associated with less bleeding and vascular injury risks compared with DAC.[70-73]

Conversion to classic sternotomy due to adverse MIAS events and its impact on clinical outcome

The incidence of MIAS conversion to CSA due to adverse intra-operative events ranges considerably, with experienced centres reporting an incidence of 3.0%[64] - 3.7%.[17] The group from Aalst suggested an increased mortality associated with conversion during PAS[64] and also reported their individual conversion rates in the context of complex isolated AVV endocarditis (9.1%),[74] redo-PAS after previous PAS (19.2%),[75] difficult access congenital chest wall deformities (0%),[76] extreme obesity (0%),[77] post-cardiac transplantation (0%)[78] and hypertrophic obstructive cardiomyopathy with associated AVV disease (0%).

Neurological events

Seeburger and his team observed postoperative neurological impairment in 3.1% of their MIAS series,[17] of which 2.1% and 1.0% were classified as minor and major neurological events (NE) respectively. Various studies report no difference in NE,[49,56] transient neuropathy[53] or permanent NE[65] incidence between MIAS and CSA, while isolated reports of a decreased NE incidence following MIAS are also documented.[17,44] However, the recent Society of Thoracic Surgeons-Adult Cardiac Surgical Database (STS-ACSD) report,[61] supported by the Consensus Statement of the International Society of Minimally Invasive Coronary Surgery (ISMICS) 2010[79] and other reports,[55-57,59-60] suggest that MIAS does indeed increase NE risk by 0.9% compared to CSA. Retrograde femoral cannulation was not considered to be an independent predictor of NE.

In addition to pre-operative vascular screening, refinements in de-airing techniques under TEE guidance and operative field CO2 flooding resulted in improved neurological outcomes.[79] The team from Aalst reported a NE incidence of 1.2% for their PAS series of 2 872 patients.[64] MIAS strategies that utilise antegrade perfusion have low NE risk and excellent outcomes. Recent multi-institutional reports suggest no significant difference in NE between EABO and DAC.[70-73]

Cardiac complications

Various studies compared cardiac outcomes between MIAS and CSA and did not identify any significant difference in the incidence of peri-operative myocardial infarction, low cardiac output syndrome, tamponade or inotropic requirements.[52-53, 57] For PAS, the group from Aalst reported their incidence of cardiac death (0.2%), acute myocardial infarction (0.7%) and low cardiac output syndrome (1.0%) in their series of 2 872 patients.[64]

A 10% incidence of post-operative atrial fibrillation (POAF) was reported for PAS in the PAIR registry, which is lower than CSA reports.[80] Mihos suggested that MIAS for isolated valve surgery reduces postoperative AF and resource use when compared with CSA.[81] Dogan[52] and Chitwood[44] suggested no difference in permanent post-operative pacemaker requirements between MIAS and CSA.

Post-operative bleeding and transfusion requirements

Extensive post-operative transfusions (POT) and re-exploration for bleeding (RE) are associated with increased mortality and morbidities.[82] Dogan and his colleagues reported significant decrease in chest drain output in MIAS compared to CSA,[52] which was reconfirmed by Glower[56] and other comparative reports.[53-55]

It is suggested that the packed red cell units transfused are less with MIAS compared with CSA,[53-55] but the percentage of patients transfused is similar.[52-55,61] Various studies also confirm a significant reduction in RE for bleeding with MIAS compared to CSA,[65,83-85] with the group from Leipzig reporting their RE rate of 5.1%.[17]

Respiratory morbidities

Comparative reports identified no significant difference between MIAS and CSA with regard to the development of post-operative pneumonia, pneumothorax, pleural effusion or other pulmonary complications[86] and it is suggested that ventilation time and subsequent intensive care stay, is significantly reduced with MIAS.[55-60]

Gastro-intestinal events

Comparative reports identified no significant difference between MIAS and CSA with regard to the development of post-operative gastro-intestinal events.[44, 53]

Renal dysfunction

McCreath and his colleagues[87] observed a highly significant independent association between surgical approach and renal function, indicating a greater risk of acute renal injury in CSA compared to MIAS performed by PAS, and suggested that PAS may be preferable to conventional methods for patients with high renal risk. Other comparative reports however, identified no significant difference in post-operative renal failure between MIAS and CSA.[57,61]

Wound infection

In a comparative report by Grossi and his colleagues, wound infection occurred in 0.9% and 5.7% of MIAS and CSA patients respectively, which increased to 1.8% for MIAS and 7.7% for CSA in the elderly.[88] Felger, however, reported no significant difference.[53] Interestingly, the risk of developing mediastinitis[57] and wound dehiscence[59] is reported to be the same for MIAS and CSA. The impact and potential benefit of MIAS in immune-suppressed patients with AVV disease is not yet reported and may indicate a potential wound healing advantage compared with CSA in developing countries.

Duration of hospital stay

It is suggested that MIAS is associated with decreased intensive care stay, total hospital duration and resource usage compared to CSA.[89-92] However, in-hospital stabilisation of anti-coagulation regimes and completion of a 6-week antibiotic course in cases of infective endocarditis, does not reflect the isolated impact on hospitalisation of MIAS.[74-78]

In-hospital mortality

Contemporary reports do not suggest a significant all-cause in-hospital mortality difference between MIAS and CSA[52-63] or EBAO and DAC.[70-73] The group from Aalst reported a peri-operative mortality of 2.6% for their PAS series.[64]

Post-discharge survival

Limited comparative reports on long term risk of all-cause mortality between MIAS and CSA are available and do not identify a significant 1- and 3-year survival difference.[45] The group from Aalst reported the intermediate- and long-term PAS survival in the context of infective endocarditis (mean 63.2 ± 42.5 months, 69.4% at 10 years),[74] extreme obesity (mean 39.4 ± 88.4 months, 100%),[76] left ventricle outflow tract resection and AVV surgery (mean 49.7 ± 30.0, 100%) and redo-PAS after previous PAS (mean 48.3 ± 39.2, 95.8% at 5 years).[75]

Freedom from readmission and reintervention

No significant difference between MIAS and CSA readmission within 30 days, risk of endocarditis or recurrence or need for valve related re-intervention are reported.[44,57,59]

Quality of life and patient satisfaction

Compared with CSA, small thoracic incisions are associated with less pain, discomfort, and postoperative analgesic requirements.[33,53] The group from Aalst suggested that more than 98% of the patients were extremely pleased with the cosmetic result of PAS, with 42% reporting an invisible scar, 93% favourably assessing procedure-related pain and 34% fully recovered within 4 weeks.[4,16] Faster recovery of patients undergoing MIAS compared to CSA was demonstrated by Glower and his colleagues[56] and it is also reported that patients undergoing MIAS as their second procedure all perceived a faster and less painful recovery than their original CSA,[53] with a small but significant decrease in NYHA class after 1 year in favour of MIAS compared to CSA.[57-65] The impact of MIAS specific to young patients and rapid recovery are not yet defined and may offer a potential advantage in return to normal duty and productivity in both high-income and low- and middle-income countries compared to CSA.

Healthcare economic implications of MIAS and CSA

Comprehensive cost-effectiveness analysis of the incremental costs and benefits of MIAS compared to CSA are limited. Atluri and his colleagues demonstrated no difference in total cost (operative and postoperative) between MIAS and CSA[93] and concluded that MIAS can be performed with overall equivalent cost and shorter hospital stay relative to CSA, as the greater operative cost is offset by shorter intensive care unit and hospital stays. Santana demonstrated that MIAS resulted in significant reductions in costs of cardiac imaging and laboratory tests, lower use of blood products, fewer peri-operative infections, faster recovery, shorter hospital length of stay, fewer requirements for rehabilitation and lower readmission rates in the following post-operative year, and concluded that MIAS is safe, effective and significantly more cost-effective than CSA.[94] Grossi suggested that MIAS provides similar mortality, less morbidity, fewer infections, shorter stay, and significant cost savings during primary admission compared to CSA, which translate into additional institutional cost savings.[95] The limited healthcare resources in developing countries may benefit from MIAS and further investigations are warranted.

APPLICATION OF MIAS IN GENERAL SURGICAL PRACTICE – OVERCOMING THE LEARNING CURVE

Holzney and his colleagues[63] assessed the individual MIAS learning process from 3 895 operations performed by 17 surgeons by analysing operation time and complication rates using sequential probability cumulative sum failure analysis. They identified the typical number of operations to overcome the learning curve as ranging between 75 and 125 procedures, and further suggested that more than 1 procedure per week is required to maintain acceptable results. In addition, they reported that the Individual learning curves varied markedly, proving the need for good monitoring or mentoring in the initial phase.

De Praetere and his colleagues from Leuven[62] assessed the MIAS learning curve by using a logarithmic curve-fit regression analysis of the CPB times, procedure complexity and the number of concomitant procedures. They reported the learning curve to be 30 procedures, with a significant reduction in aortic cross-clamp time before and after the end of the learning curve. The complexity of AVV reconstruction gradually increased and proportion of mitral valve replacements decreased by gradually expanding MIAS indications. They concluded that the transition from CSA to MIAS could safely be introduced into practice without mortality, longer intensive care or hospitalisation.

Hunter reported a systematic approach on how to initiate a MIAS programme[96] and identified techniques of AVV repair, TEE-guided cannulation, incisions, instruments, visualisation, aortic occlusion and CPB strategies as seven key aspects to master during the learning curve. He also emphasised the principles of systems awareness, teamwork, communication, ownership and leadership – all of which are paramount to performing safe and effective MIAS.

Murzi[97] applied control charts (CUSUM curves) to monitor individual MIAS surgeon outcomes, with a predetermined acceptable failure rate, alert and alarm lines and clear procedure failure definitions. They identified significant inter-surgeon learning curve variation and concluded that the transition toward MIAS can be performed with low morbidity and mortality.

CONCLUSION

CSA for AVV disease is well established, but its role in contemporary clinical practice are continuously being redefined by rapid evolution in trans-catheter and MIAS technology, patient preference and industry-driven marketing. However, the routine application of MIAS is met with varying degrees of enthusiasm in view of learning curves, strict quality control, clinical governance and outcome reporting. It is therefore imperative that contemporary international MIAS outcomes are meticulously evaluated for evidence of well-defined patient and healthcare economic benefits – before adopting these techniques into clinical practice. This review confirms the historically reported potential benefits of MIAS compared with CSA and comparable efficacy across a range of long-term efficacy measures such as freedom from reoperation and long-term survival. Surgeons should be encouraged to adopt and apply MIAS in an exciting era of progressive trans-catheter intervention preference, whether in a first- or third-world clinical context.

Conflict of interest: none declared.

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