Southern African Journal of Anaesthesia and Analgesia. 2021;27(6 Suppl 1):S111-117
https://doi.org/10.36303/SAJAA.2021.27.6.S1.2688

South Afr J Anaesth Analg
ISSN 2220-1181 EISSN 2220-1173

FCA REFRESHER COURSE

Anaesthesia for minimally invasive cardiac surgery

N Manitshana

School of Clinical Medicine, Faculty of Health Sciences, University of the Witwatersrand, South Africa
Corresponding author, email: *drntsiki@live.com*

Keywords: minimally invasive cardiac surgery, anaesthesia, mini-sternotomy, robotic-assisted cardiac surgery

Introduction

Cardiac surgery is a complex field with ever-evolving techniques and technologies aimed at improving outcomes. It has developed rapidly since the 1950s when it was still associated with high morbidity and mortality. Some of the first cases of minimally invasive cardiac surgery (MICS) were performed in the 1990s, when laparoscopic general surgery was rapidly growing in popularity.[1,2] MICS has evolved tremendously since then and currently even includes robotic surgery. Although there is still no consensus on the definition, MICS can be thought of as cardiac surgery through several small thoracic or sternal incisions instead of the conventional full median sternotomy, in an effort to avoid complete sternal splitting and even cardiopulmonary bypass, when feasible.[1,3,4]

There are only a limited number of randomised control trials that have been undertaken to evaluate the difference in outcomes of the conventional full sternotomy compared to MICS.[5] There is no significant difference in morbidity and mortality between the two approaches that has been demonstrated.[6] A recent systematic review echoed the same opinion, that MICS is as safe as conventional median sternotomy.[7] On the other hand, trials comparing surgical aortic valve replacement (SAVR) with transcatheter aortic valve implantation (TAVI) have shown significantly better outcomes with TAVI.[8-10]

Types of minimally invasive cardiac surgery

- Cardiac surgery on the beating heart without cardiopulmonary bypass (CPB):
  - Transcatheter approaches (TAVI)
  - Minimally invasive direct coronary artery bypass (MIDCAB)[11]
  - Off-pump coronary artery bypass (OPCAB)
- Cardiac surgery via port access with video assistance and peripheral (percutaneous) CPB:
  - Totally endoscopic coronary artery bypass (TECAB)[12]
  - Robotic-assisted cardiac surgery (RACS)[1,13]
- Minimally invasive thoracic approaches to the mitral and aortic valves and atria, via mini-sternotomy or thoracotomy

Currently in South Africa, there is widespread use of the seemingly outdated conventional cardiac surgery techniques. The Western Cape Province has already jumped onto the MICS bandwagon.[14] It is only recently that TAVI programmes have been introduced into the public sector in Johannesburg, Gauteng Province. The delayed adoption of new strategies may be due to various factors, including poor outcomes with conventional cardiac surgery.

A retrospective study done at a Johannesburg tertiary hospital, revealed a perioperative mortality rate of 11.2% for conventional median sternotomy for coronary artery bypass graft (CABG). This rate exceeds that which is reported in other countries.[15] The contributing perioperative complications included sternal sepsis, bleeding and prolonged ventilation. These complications have been reported as being less common with minimally invasive techniques.[6] This would therefore support the recommendation of adoption of novel minimally invasive techniques, which could potentially result in the improvement of these perioperative outcomes.[15]

The progression towards MICS was also propelled by complications related to conventional full sternotomy, which include the following:

- Prolonged recovery (longer ICU stay)
- Sternal sepsis
- Excessive pain leading to immobility, thus increased risk of respiratory complications
- Poor wound healing
- Unsightly scarring
- Wound infection
- Brachial plexus palsies
- Chronic pain syndromes
- Respiratory dysfunction[11,16]

Aortic manipulation during cannulation and clamping increases the risk of dissection, arterial embolisation, and stroke.[17]

Advantages of minimally invasive cardiac surgery

- Shorter ICU stay supports enhanced recovery concepts
- Better cosmesis and patient satisfaction
- Less pain
- Quicker resumption of normal activities

- Reduced blood loss
- Less inflammation
- Less blood transfusion
- Less invasive[5]

All these factors contribute to lower costs.

Disadvantages of minimally invasive cardiac surgery

- Minimally invasive surgery requires specialised high-end medical equipment
- Surgeons need specialised training beyond basic cardiac surgery
- Smaller operating regions and therefore reduced surgical exposure, unless it is video-enhanced surgery
- Intravascular injury from percutaneous cannulation (carries a higher risk than central cannulation)[11]
- Aortic clamping and de-airing of the heart is more challenging
- Cannulae may dislodge atheromatous debris and cause thromboembolic phenomena[16]
- Longer duration of surgery
- Requires careful patient selection[16]
- Requires advanced anaesthesia skills in transoesophageal echocardiography (TEE) and multimodal analgesia[3]
- Bulky equipment that limits access to patient[18]

Contraindications to minimally invasive cardiac surgery

Relative	Absolute
1. Previous radiotherapy	1. Any contraindication to TEE (such as oesophageal webs, varices, tumours, strictures, lacerations or upper GI bleeding)
2. Pleural adhesions	2. Aortic aneurysm > 40 mm
3. Thoracic surgery	3. Diffuse coronary artery occlusion
4. Chest wall deformities (incl. kyphoscoliosis)	4. Calcified mitral annulus or calcified aorta
5. Rib trauma	5. Severe ventricular dysfunction
6. History of radiation to the head, neck or mediastinum	6. Severe pulmonary hypertension
7. Previous surgery of the upper GI tract, oesophageal, active peptic ulcer disease or hiatal hernia	7. Narrow aorta (< 25 mm diameter)[5,11]
8. BMI < 18 or > 35 kg/m^2 not ideal for TECAB and RACS[1,3]	
9. Peripheral vascular disease	
10. Aortic atheroma	
11. Previous cardiac surgery[16]	

This list is by no means exhaustive

Anaesthetic approach to minimally invasive cardiac surgery

The anaesthetic technique for MICS depends on the nature of the surgery, the surgical approach and the perfusion strategies (beating or non-beating heart, central or peripheral cannulation or type of cardioplegia).[16]

However, the basic aims of cardiac anaesthesia still have to be adhered to when performing MICS. There has to be haemodynamic stability, organ protection and maintenance of oxygenation. In order to facilitate surgery, one lung ventilation (OLV) may also be required. The anaesthesiologist is also responsible for the performance of TEE to guide CPB cannulae, to confirm suitability of vessel diameters, to evaluate size or atheromatous disease in the aorta, identify catheter migration, identify complications and cardiac defects, cardiac catheters and vents. Most importantly, TEE is required to guide endo-aortic balloon positioning, which is essential for adequate and safe delivery of cardioplegia.[3,16] De-airing of the heart also relies on TEE guidance and is done through an aortic or a left ventricular vent.[19]

The establishment of a multidisciplinary team is an absolute pre-requisite. It should be composed of the anaesthesiologist, cardiologist, cardiothoracic surgeon, perfusionist, ICU team and theatre/hybrid suite nursing team. The theatre should also be specifically equipped for MICS. Commonly hybrid theatres are utilised for MICS. This is followed by careful patient selection.

Preoperative requirements

Traditional clinical evaluation for full sternotomy, composed of thorough history, examination and investigations will have to be performed to confirm suitability of the patient and procedure. Haematological and radiological investigations should be followed by assessment of suitability for OLV.[3]

Computerised tomography scans of the heart and vessels are essential for patient risk stratification and assessment of severity of the lesion and any anatomical abnormalities.[20] They are also essential for assessing flow, presence of atheromatous plaques, diameter and tortuosity of vessels, which could hinder peripheral cannulation. This will elucidate whether the vessels are suitable for minimally invasive techniques or not.[5] Carotid studies may also help evaluate the risk of perioperative strokes.[1]

Chest X-rays, pulmonary function tests and arterial blood gas measurements are required in order to assess the risk of postoperative pulmonary complications. Cessation of smoking and optimisation of bronchodilation therapy must also be instituted for at least two weeks prior to MICS. MICS generally will require prolonged OLV and carbon dioxide insufflation, thus patients with resting hypercarbia (> 50 mmHg) and hypoxia (< 65 mmHg) are unlikely to tolerate MICS.[21,22]

Preoperative echocardiography is required for the assessment of the cardiac pathology, right ventricular size, function and pressures, especially because OLV can worsen any pre-existing pulmonary hypertension.[3]

The patient must also be meticulously counselled about all the perioperative events, as well as the risk of conversion to full sternotomy and its potential complications. Comprehensive informed consent must be obtained. An anxiolytic premedication is also recommended when there are no contraindications.[16]

Intraoperative considerations

Prior to induction, the position of the patient during surgery must be confirmed and adequate padding should be made available. Inadequate protection of pressure points may cause nerve injuries. Warming devices should also be available because normothermia is required for early extubation.[16]

The standard cardiac surgery monitoring: TEE, depth of anaesthesia, temperature, 5-lead ECG, urine output, cerebral oximetry, arterial pressure (may be required bilaterally if an endo-aortic occlusion device will be utilised) and central venous pressure. This would thus require four pressure transducers, for the two arterial lines, CVP and the tip of endo-aortic balloon (for aortic occlusion). The vascular access sites that may be required for surgery, must be confirmed prior to insertion of invasive lines.[21] External defibrillator pads should be attached because use of internal paddles is not feasible during MICS. Occasionally the thoracic impedance may be too high during OLV thus hindering delivery of defibrillation. In this situation, reinflation of the collapsed lung is required.[3]

For surgery involving the right atrium, the anaesthetist may be requested to insert a large bore right internal jugular venous cannula for SVC drainage. This has to be preceded by administration of 10 000u of heparin, absolute sterility, as well as TEE confirmation of placement.[11]

Sometimes access to the patient and the airway may be limited due the sheer size of the MICS equipment, therefore, endotracheal tubes should be well-secured and pressure points should be rechecked before incision.[18]

A cardiac-stable induction should precede insertion of a double-lumen tube or single-lumen tube with a bronchial blocker.[11] Profound muscle relaxation will be required for absolute immobilisation.[21]

The intra-thoracic insufflation of CO_2 is to facilitate adequate visualisation of surgical site. The insufflation pressures must be kept below 10 mmHg to avoid a decrease in venous return and cardiac output, especially in a patient with severe ventricular dysfunction.[11]

All the valves except the pulmonary are accessible through a mini-sternotomy.[5] Conversion to full sternotomy from a minimally invasive approach has been shown in various studies to range between 2–15% depending on the surgical approach employed.[12,19,23]

When peripheral CPB is required, it is important to confirm under ultrasound guidance that the aortic cannula is of a smaller diameter than the femoral artery before the surgeons embark on its insertion. Thereafter the TEE will be required to guide the guidewire, then the cannula into its correct position in the aorta. Aortic rupture, dissection or intimal tears need to be avoided at all costs as they would result in the need for immediate conversion to full sternotomy and possibly deep hypothermic arrest.[16]

In the event of hypoxaemia from OLV during MICS for valvular lesion, conversion to normal bilateral lung ventilation and conversion to full sternotomy is recommended.[1,16]

Multimodal analgesia is indispensable in MICS patients because the pain is comparable to that of a thoracotomy. Some centres have embarked on regional blocks for thoracic incisions, however, there are concerns about systemic heparinisation in such situations, unless they are performed at the end of the procedure.[11,16]

Postoperative considerations

The postoperative management is similar to conventional cardiac surgery, however, more emphasis is placed on enhanced recovery strategies. It is essential to assess for signs of organ dysfunction and impaired perfusion of extremities. Arterial insufficiency post percutaneous cannulation is a real possibility. Adequate pain control must be maintained to encourage early mobilisation. Vigilance for the various complications associated with cardiac surgery is a necessity.

Minimally invasive direct coronary artery bypass

Minimally invasive direct coronary artery bypass (MIDCAB) grafting is ideal for the grafting of the left internal mammary artery to the left anterior descending artery. A left anterior mini-thoracotomy is performed to create just enough space for only one or two coronary vessels grafts.[5] It is performed as an off-pump technique, thus avoiding the complications of CPB. This leads to faster recovery times and therefore a reduced stay in ICU.[11]

The avoidance of CPB and aortic instrumentation results in lower incidence of post-CABG cognitive dysfunction. The trade-off is the longer intraoperative periods. However, even that is negated by the shorter hospital stay.[21]

Robotic-assisted cardiac surgery

These novel techniques are rapidly evolving the landscape of surgical interventions. The common robotic system used is called the Da Vinci®. It is an advancement of TECAB. The surgeon is seated within a console away from the operating table and the patient. This console has devices that connect to his/her hands and feet, which can then duplicate his/her movements. This method is also better described as “telemanipulation”. The surgeon can see the patient but is not within reach due to the bulkiness of all the robotic equipment, thus relies on the high-resolution viewing screens and robotic arms. The system has multiple limbs which can be used for cutting, suturing and retracting. The surgeon needs specialised skill and dexterity in order to delicately manoeuvre these instruments.[24] The anaesthesiologist needs advanced skills in TEE.[18]

The anaesthetic technique adopted by Murkin and Ganapathy involved a general anaesthetic with a rocuronium infusion and a thoracic paravertebral block for robotic-assisted visually-enhanced coronary artery bypass (RAVECAB). This type of robotic surgery may take up to 4–6 hours.[21,22] Conversion to full sternotomy only occurred in 3–5% of cases.[21]

The indications include:

- Single or dual-vessel CABG
- Mitral valve repair
- Intracardiac tumour resection

Considerations

- Appropriate and careful patient selection is extremely important for surgeons and institutions offering a robotic cardiac surgery programme.[25]
- Limited workspace and access to patient's airway. In the event of emergency, moving robotic system may prove challenging.
- Patient position is a slight right lateral tilt with the left arm suspended cephalad. The operative areas may include the thorax, both groins and one upper limb. This issue will require comprehensive discussion because of limited options for IV lines and the use of an endo-aortic occlusion balloon may necessitate bilateral radial arterial lines.[18]
- Profound muscle relaxation for absolute immobilisation.
- OLV and intrathoracic CO_2 insufflation (development of tension pneumo/capnothorax will require decompression).
- Percutaneous cannulation at femoral (or axillary) vessels. Poses higher risk of complications.
- Additional large bore jugular vascular access.
- De-airing of the heart may be challenging (requires flooding of surgical field with CO_2).
- Vacuum may be used to improve venous drainage (risk of airlocks and haemolysis).
- Ventricular epicardial pacing wires will also need to be placed, as per conventional cardiac surgery.
- Regional blocks or intercostal blocks may be performed at the end of the procedure.

Figure 1: Da Vinci Robotic Surgery console (Intuitive Surgical, Sunnyvale, CA, USA)[18]

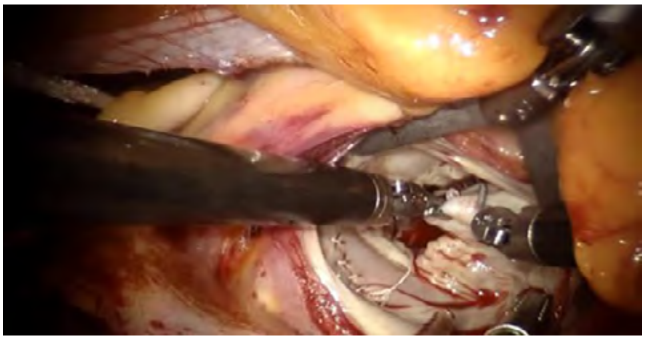

Figure 2: Robotic mitral valve repair using the Da Vinci System (Intuitive Surgical, Sunnyvale, California, USA)[18]

Complications

- Endo-aortic balloon migration or rupture.
- Arrhythmias and myocardial dysfunction during protracted OLV.

Transcatheter aortic valve replacement

TAVI refers to an endovascular procedure performed with fluoroscopic guidance. It was originally reserved for patients who were deemed high-risk for SAVR. It is commonly performed by interventional cardiologists, with the cardiothoracic team on stand-by.

Most studies done in South Africa assessed the cost-effectiveness of TAVI versus medical management of AS and were done in the private sector in the Western Cape Province.[26] They showed that SAVR had 21.4% higher in-hospital mortality than TAVI.

Considerations

- Remote site anaesthesia and exposure to radiation. As well as careful patient selection (Table I).
- The anaesthesia needs to be approached in a minimalist fashion to facilitate fast-track pathways. Choice between GA or sedation depends on the institutional practices.
- Heparin 80 U/kg must be administered upon insertion of sheath into femoral vessels.
- Ensure patient is well sedated (BIS 60–70) to limit risk of unexpected movement during valve deployment.
- Upon confirmation of position, rapid ventricular pacing (heart of 180 bpm or more) is initiated (in order to minimise cardiac ejection and 'native' valve movement) then the 'prosthetic' valve is deployed via balloon inflation and rapid deflation.
- Transient hypotension and arrhythmias may occur during this period (lasting 10–15 seconds). It is essential to delay intervening to allow the prosthetic valve to settle.
- Once deployed, the valve position and patency of the coronary ostia must be confirmed.

The complications include vascular injury, pericardial haemorrhage, conduction system abnormalities, arrhythmias, valve mal-positioning/migration, cerebrovascular accidents and renal dysfunction.

Table I: Criteria for TAVI vs SAVR[27]

	Favours TAVI	Favours SAVR
Clinical characteristic		
STS/EuroSCORE II < 4% (logistic EuroSCORE 1 < 10%)		+
STS/EuroSCORE II ≥ 4% (logistic EuroSCORE 1 ≥ 10%)	+	
Presence of severe comorbidity (not adequately reflected by scores)	+	
Age < 75 years		+
Age ≥ 75 years	+	
Previous cardiac surgery	+	
Frailty	+	
Restricted mobility and conditions that may affect the rehabilitation process after the procedure	+	
Suspicion of endocarditis		+
Anatomical and technical aspects		
Favourable access for transfemoral TAVI	+	
Unfavourable access (any) for TAVI		+
Sequelae of chest radiation	+	
Porcelain aorta	+	
Presence of intact coronary bypass grafts at risk when sternotomy is performed	+	
Expected patient–prosthesis mismatch	+	
Severe chest deformation or scoliosis	+	
Short distance between coronary ostia and aortic valve annulus		+
Size of aortic valve annulus out of range for TAVI		+
Aortic root morphology unfavourable for TAVI		+
Valve morphology (bicuspid, degree of calcification, calcification pattern) unfavourable to TAVI		+
Presence of thrombi in aorta or LV		+
Cardiac conditions in addition to aortic stenosis that require consideration for concomitant intervention		
Severe CAD requiring revascularisation by CABG		+
Severe primary mitral valve disease, which could be treated surgically		+
Severe tricuspid valve disease		+
Aneurism of the ascending aorta		+
Septal hypertrophy requiring myectomy		+

Figure 3: Deployment of valve via balloon inflation for expansion of valve with supportive frame. Guidewire inserted retrograde from femoral artery into aorta and extending into left ventricle.

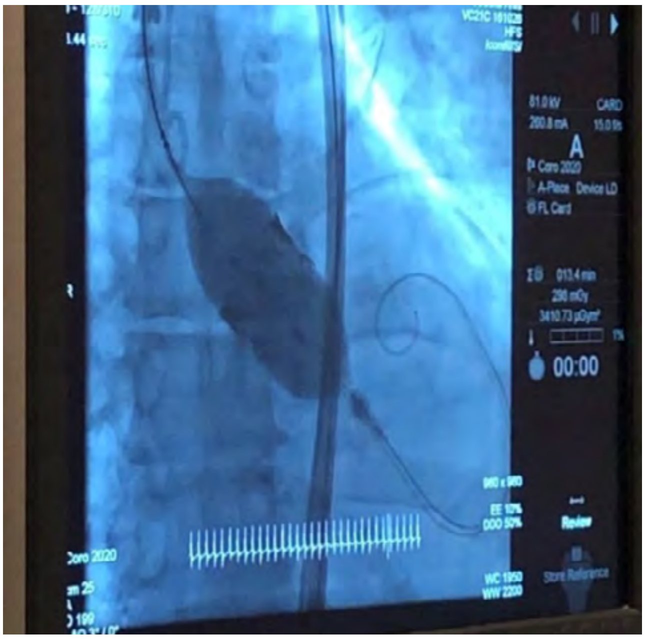

Figure 4: Fully deployed and expanded valve. Continuous rapid ventricular pacing (RPC).

Figure 5: Deflation of balloon

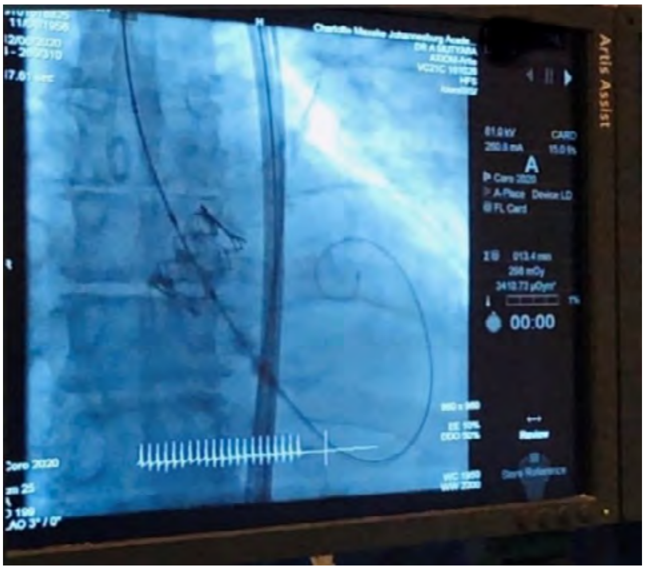

Figure 6: Confirmation of valve placement and complete balloon deflation, with supportive frame of valve visualised at aortic annulus. Cessation of RPC.

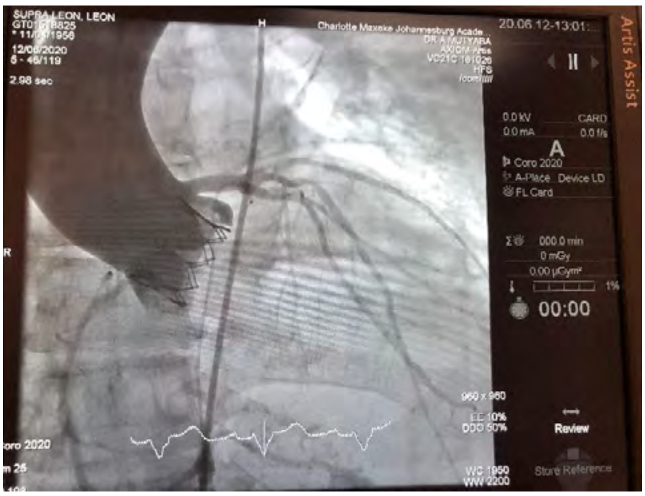

Figure 7: The final aortogram with prosthetic valve in situ and patent coronaries.

Conclusion

MICS is growing rapidly and healthcare workers have to embrace progress. There are various elements that have to be considered and accommodated in order to ensure good outcomes. The limited data on outcomes is promising nevertheless.

These novel developments not only benefit the patients, but the healthcare workers too. They have an opportunity to fine-tune working relations, acquire new skills, be exposed to new challenges and also be positive contributors to medical evolution.

Conflict of interest

Nothing to declare.

ORCID

N Manitshana https://orcid.org/0000-0002-8264-9916

References

1. Balasubramanyam U, Kapoor PM. Anesthetic challenges in minimally invasive cardiac surgery. J Card Crit Care. 2020;3(01):28-35. https://doi.org/10.1055/s-0039-3401464.
2. Cosgrove DM, Sabik JF, Navia JL. Minimally invasive valve operations. Ann Thorac Surg. 1998;65(6):1535-8; discussion 8-9. https://doi.org/10.1016/S0003-4975(98)00300-2.
3. White A, Patvardhan C, Falter F. Anesthesia for minimally invasive cardiac surgery. J Thorac Dis. 2021;13(3):1886-98. https://doi.org/10.21037/jtd-20-1804.
4. Duhaylongsod FG. Minimally invasive cardiac surgery defined. Arch Surg. 2000;13(3):296-301. https://doi.org/10.1001/archsurg.135.3.296.
5. Doenst T, Diab M, Sponholz C, Bauer M, Färber G. The opportunities and limitations of minimally invasive cardiac surgery. Dtsch Arztebl Int. 2017;114(46):777-84. https://doi.org/10.3238/arztebl.2017.0777.
6. Cheng DCH, Martin J, Lal A, et al. Minimally invasive versus conventional open mitral valve surgery: a meta-analysis and systematic review. Innovations. 2011;6(2):84-103. https://doi.org/10.1097/imi.0b013e3182167feb.
7. Dieberg G, Smart NA, King N. Minimally invasive cardiac surgery: A systematic review and meta-analysis. Int J Cardiol. 2016;223:554-60. https://doi.org/10.1016/j.ijcard.2016.08.227.
8. Kapadia SR, Leon MB, Makkar RR, et al. 5-year outcomes of transcatheter aortic valve replacement compared with standard treatment for patients with inoperable aortic stenosis (PARTNER 1): a randomised controlled trial. Lancet. 2015;385(9986):2485-91. https://doi.org/10.1016/S0140-6736(15)60290-2.
9. Leon MB, Smith CR, Mack MJ, et al. Transcatheter or surgical aortic-valve replacement in intermediate-risk patients. N Engl J Med. 2016;374(17):1609-20. https://doi.org/10.1056/NEJMoa1514616.
10. Duarte Ferreira H, Carvalheiro C, Sena A, et al. Minimally invasive approach vs full sternotomy for aortic valve and ascending aorta replacement: results from our center. Rev Port Cir Cardiotorac Vasc. 2018;25(1-2):35-40.
11. Parnell A, Prince M. Anaesthesia for minimally invasive cardiac surgery. BJA Educ. 2018;18(10):323-30. https://doi.org/10.1016/j.bjae.2018.06.004.
12. Dogan S, Aybek T, Mierdl S, Wimmer-Greinecker G. Totally endoscopic coronary artery bypass grafting on the arrested heart is a prerequisite for successful totally endoscopic beating heart coronary revascularisation. Interact Cardiovasc Thorac Surg. 2002;1(1):30-4. https://doi.org/10.1016/S1569-9293(02)00008-7.
13. Gayes JM. The minimally invasive cardiac surgery voyage. J Cardiothorac Vasc Anesth. 1999;13(2):119-22. https://doi.org/10.1016/S1053-0770(99)90072-1.
14. Van der Merwe J, Casselman F, Van Praet F. Minimally invasive atrioventricular valve surgery-current status and future perspectives. South African Heart Journal. 201916(4):310-6. https://doi.org/10.24170/16-4-3842.
15. Reiche S, Mpanya D, Vanderdonck K, et al. Perioperative outcomes of coronary artery bypass graft surgery in Johannesburg, South Africa. J Cardiothorac Surg. 2021;16(7):7. https://doi.org/10.1186/s13019-020-01385-8.
16. Malik V, Jha AK, Kapoor PM. Anesthetic challenges in minimally invasive cardiac surgery: Are we moving in a right direction? Ann Card Anaestha. 2016;19(3):489-97. https://doi.org/10.4103/0971-9784.185539.
17. Ramchandani M, Al Jabbari O, Abu Saleh WK, Ramlawi B. Cannulation strategies and pitfalls in minimally invasive cardiac surgery. Methodist DeBakey Cardiovasc J. 2016;12(1):10-3. https://doi.org/10.14797/mdcj-12-1-10.
18. Bernstein WK, Walker A. Anesthetic issues for robotic cardiac surgery. Ann Card Anaesth. 2015;18(1):58-68. https://doi.org/10.4103/0971-9784.148323.
19. Salenger R, Gammie JS, Collins JA. Minimally invasive aortic valve replacement. J Card Surg. 2016;31(1):38-50. https://doi.org/10.1111/jocs.12652.

20. Dearani JA. Robotic heart surgery: Hype or hope? J Thorac Cardiovasc Surg. 2018;155(1):77-8. https://doi.org/10.1016/j.jtcvs.2017.09.063.
21. Murkin JM, Ganapathy S. Anesthesia for robotic heart surgery: an overview. Heart Surg Forum. 2001;4(4):311-4.
22. Slinger PD, Johnston MR. Preoperative evaluation of the thoracic surgery patient. Seminars in Anesthesia, Perioperative Medicine and Pain. 2002;3:168-81. https://doi.org/10.1053/sane.2002.34192.
23. Tabata M, Umakanthan R, Khalpey Z, et al. Conversion to full sternotomy during minimal-access cardiac surgery: Reasons and results during a 9.5-year experience. J Thorac Cardiovasc Surg. 2007;134(1):165-9. https://doi.org/10.1016/j.jtcvs.2007.01.077.
24. Kaplan J, Cronin B, Maus T, editors. Kaplan's essentials of cardiac anesthesia for cardiac surgery. 2nd ed. Philadelphia, USA: Elsevier; 2018.
25. Gilbert R, Inderbitzi C, Schmid RA, Melfi F. Minimally invasive thoracic and cardiac surgery. Berlin, Heidelberg: Springer; 2012. https://doi.org/10.1007/978-3-642-11861-6.
26. Mabin TA, Condolfi P. An analysis of real-world cost-effectiveness of TAVI in South Africa. Cardiovasc J Afr. 2014;25(1):21-6. https://doi.org/10.5830/CVJA-2013-090.
27. Baumgartner H, Falk V, Bax JJ, et al. 2017 ESC/EACTS Guidelines for the management of valvular heart disease. Eur Heart J. 2017;38(36):2739-91. https://doi.org/10.1093/eurheartj/ehx391.