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Consensus statement on aortic valve replacement via an anterior right minithoracotomy in the UK healthcare setting

Hunaid A Vohra,[1] M Yousuf Salmasi ,[2] Fatemazahra Mohamed,[3] Monica Shehata,[4] Bardia Bahrami,[4] Massimo Caputo ,[1] Ranjit Deshpande,[5] Vinayak Bapat,[6] Toufan Bahrami,[4] Inderpaul Birdi,[7] Joseph Zacharias [8]

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[1]Bristol Royal Infirmary, Bristol, UK
[2]Surgery and Cancer, Imperial College London, London, UK
[3]Imperial College London, London, UK
[4]Royal Brompton and Harefield Hospitals, London, UK
[5]Cardiology, King's College Hospital, London, UK
[6]Cardiovascular Directorate, Guy's & St Thomas' Hospitals NHS Foundation Trust, London, UK
[7]Basildon and Thurrock University Hospitals NHS Foundation Trust, Basildon, UK
[8]Lancashire Cardiac Centre, Blackpool Victoria Hospital, Blackpool, UK

Correspondence to
Dr M Yousuf Salmasi; y.salmasi@imperial.ac.uk

ABSTRACT

The wide uptake of anterior right thoracotomy (ART) as an approach for aortic valve replacement (AVR) has been limited despite initial reports of its use in 1993. Compared with median sternotomy, and even ministernotomy, ART is considered to be less traumatic to the chest wall and to help facilitate quicker patient recovery. In this statement, a consensus agreement is outlined that describes the potential benefits of the ART AVR. The technical considerations that require specific attention are described and the initiation of an ART programme at a UK centre is recommended through simulation and/or use of specialist instruments in conventional cases. The use of soft tissue retractors, peripheral cannulation, modified aortic clamping and the use of intraoperative adjuncts, such as sutureless valves and/or automated knot fasteners, are important to consider in order to circumvent the challenges of minimal the altered exposure via an ART.

A coordinated team-based approach that encourages ownership of the programme by team members is critical. A designated proctor/mentor is also recommended. The organisation of structured training and simulation, as well as planning the initial cases are important steps to consider.

INTRODUCTION

The publication of outcome data relating to hospitals and individual surgeons has led to improvements in patient outcomes, despite the increasing complexity of cases.[1] In parallel, evidence-based practice has become further integrated within surgery, and 'best practice' management options can be safely presented to appropriate patients.[2] In the case of surgical aortic valve replacement (AVR), median sternotomy (MS) has historically been considered as the 'gold standard' for treatment of severe aortic stenosis (AS).

As an alternative to MS, minimally invasive AVR (MIAVR) has been implemented in high-volume centres of excellence with positive outcomes.[3] An upper hemisternotomy (or ministernotomy) has been a longer established mode of MIAVR. Numerous trials and multicentre studies have compared MS with ministernotomy, finding several benefits: lower ventilation time,[4–6] pain scores,[5 6] intensive care unit (ICU) stay[5 7] and hospital stay.[7 8] There is also evidence to suggest lower transfusion requirement with MIAVR[5] and a reduced volume of blood loss.[4 6] It is important to note that two randomised control trials did not show any advantages with the upper hemisternotomy (UHS) approach (Ministern and MAVRIC).

In comparison, the anterior right thoracotomy (ART) approach avoids any division of the sternum whatsoever, and opts instead for a smaller ~6 cm intercostal incision to the right of the sternum (figure 1). Being more technically challenging than ministernotomy, the outcomes of AVR via the ART approach have been limited to single centre studies, although they demonstrate numerous benefits, including improved patient satisfaction and reduced hospital complication rates and economic costs. Limitations to ART are related to increased technical considerations, thus causing increased operative times and surgeon's learning curve.[9–12] Although an extremely attractive option for patients in principle, its widespread uptake has been limited by the need for specialist equipment and techniques, a steep learning curve and lack of evidence base of improved equivocal outcomes when compared with gold standard.

This paper aims to comprehensively review the evidence for the implementation of the ART approach in the treatment of severe AS, in addition to offering vital considerations prior to the commencement of a novel ART-AVR programme in a UK healthcare trust.

Figure 1 Incision for anterior right thoracotomy in the third intercostal space.

EVIDENCE FOR MINIMALLY INVASIVE AORTIC VALVE SURGERY

In the literature, there is a lack of adequately powered randomised controlled data comparing ART with MS and UHS. However, among meta-analyses and observational studies, ART has demonstrated the beneficial outcomes noted in this section.[13]

Reduced postoperative bleeding

The complete avoidance of sternal bone marrow exposure and via a smaller incision leads to minimised postoperative bleeding in the ART approach.[14] Specifically, an average reduction of 191 mL of bleeding in the first 24 hours postsurgery (p<0.001) has been reported in a large propensity matched observational study (422 ART vs 422 MS) conducted by Stoliński *et al*. In addition, 18.5% fewer patients undergoing ART required blood transfusion in comparison to MS (p<0.001) and the amount of blood transfused was 229.6 mL less than the MS group (p<0.001)[15] and fewer patients required reoperation.[15]

Enhanced patient recovery

Many studies have associated ART with shorter ICU and in-hospital LOS, as well as reduced ventilation time.[9] A recent meta-analysis conducted by Chang *et al*[16] found on average reduction of 2.1 days afforded by ART compared with MS (p<0.01). This was confirmed in a subsequent meta-analysis by Salmasi *et al*[13] where ART patients were found to have a significantly shorter hospital length of stay (LOS) (mean difference: 0.12, 95% CI 0.027 to 0.22; p=0.012), despite equivalent ventilation and length of ICU stay.

The enhanced recovery offered by ART is suggested to be a result of improved thoracic stability and retained chest wall integrity, allowing for earlier mobilisation and swifter return to normal activity[15 17]: up to 93% of the patients undergoing ART are back to their normal activities within 4 weeks.[18] Patients were also more likely to experience reduced pain and discomfort.[17] and up to 96% of patients believe they have an aesthetically pleasing scar.

Reduced postoperative complications

The lower level of surgical trauma and reduced heart manipulation through an ART incision may contribute to less postoperative atrial fibrillation by up to 50%.[16 19]

Patients undergoing ART also experience significantly reduced respiratory impairment than MS, noted through spirometry analysis, increased PO_2 and less of a marked drop in PCO_2 levels, suggesting a reduced need for respiratory effort.[20]

Benefits in redo surgery

Reoperations in cardiac surgery are higher risk due to dense adhesions and risks to mediastinal structures. However, primary MIAVR will involve less manipulation of the mediastinum, such that a redo procedure, if needed, will not require extensive adhesion dissection around the heart.[21] In accordance with the previous findings, Del Giglio *et al* suggested that ART proposes a safer approach in terms of access for reoperation.[11] It is our belief that using an ART approach in the redo setting should be limited to surgeons and centres who have already established a large programme in first time ART surgery.

Reduced costs

Given the reduced LOS, complication rates and need for product transfusion, a total reduction in hospital costs is evident.[9 14 19 22] A retrospective, propensity score matched cost-analysis by Ghanta *et al*[22] discovered a 5% reduction total hospital costs for MIAVR compared with MS (p=0.02). Moreover, Rodriguez *et al*,[23] more specifically found ART to reduce the hospital costs by US$3887 compared with MS. (p<0.0001).

TRAINING AND LEARNING CURVE

Novel techniques are often associated with a steep learning curve[24] and training is required for the entire team to ensure optimal patient safety and clinical outcomes.[25 26] The majority of unsatisfactory outcomes occur at the beginning of the learning curve, with improvements in outcomes over time as surgical techniques are enhanced and experience is gained.[19] Monitoring the institution's progress through the learning curve is important, using cumulative sum (CUSUM) method, which also detects surgeon's variability and the minimum cases required.[12 27]

A number of studies have demonstrated a plateau in the learning curve after the initial cases. Brinkman *et al*[28] placed this number of cases for MIAVR at 45–50, using local weighted regression. Bethencourt *et al*[29] revealed improvements in outcomes in 202 patients using ART over the course of their study, suggesting an association

Table 1 Technical aspects of ART access aortic valve replacement surgery and relevant ways to introduce into a new unit

	Attempts on sternotomy AVR cases	Wetlab	Team based simulation	Visit to specialist centre	Visit from Proctor to unit
Mini thoracotomy		√		√	√
Aortic occlusion				√	√
Knot pushing	√	√	√	√	√
Automated knot fasteners for example, CorKnot	√	√	√	√	√
Retrograde cardioplegia/venting via internal jugular vein	√	√		√	√
Thoracoscopic adjunct	√			√	√
The use of sutureless AVR prostheses	√	√	√	√	√

ART, anterior right thoracotomy; AVR, aortic valve replacement.

with the learning curve; this included a significant improvement in operative times of 78 min on average, in addition to earlier extubation (p<0.001), less prolonged ventilation (p=0.012), decreased mean blood transfusions (p=0.011) and a shorter hospital LOS (p=0.026).[29]

Also, using specialised MIAVR equipment within conventional AVR using MS may be useful in improving success in navigating the learning curve and providing patients with safer outcomes (table 1).[24]

Surgical mentorship programmes can be organised through the provision of dedicated fellowships and mentor schemes, which can be uniquely facilitated via specialist societies, such as British and Irish Society of Minimally Invasive Cardiac Surgery and Society of Cardiothoracic Surgeons of Great Britain and Ireland. This can allow for targeted training of cardiac surgeons to promote the development of MIS cardiac surgeons. Industry partners may play an important role in supporting proctors and surgeons.

TECHNICAL CHALLENGES TO OVERCOME

Incision size

The shorter incision length gives the impression of the AoV sitting deeper within the chest.[30] The incision can be increased in length by 1–2 cm to optimise surgical exposure.[30] To enhance exposure, surgeons have the option of a number of strategies including:

1. Peripheral cannulation.
2. Strategic placement of pericardial sutures.
3. A single-lumen endotracheal tube with posterior right lung retraction is typically used in MIAVR.
4. A double-lumen endotracheal tube with single-lung ventilation.[30 31]

These strategies have the collective effect of distancing potential visceral obstructions, increasing the internal space and reducing the physical barriers in the operative field. Usually, a soft-tissue retractor (Edwards Lifesciences, Irvine, Calif, Alexis retractor, applied Medical) is introduced into the incision followed by a small rigid retractor with narrow blades (figure 2). The right internal thoracic artery (RITA) is usually divided during the initial incision, although there have been smaller reports of RITA sparing techniques described.[32] RITA-sacrificing incisions must be sure to adequately ligate and/or cauterise the vessels to prevent bleeding complications.

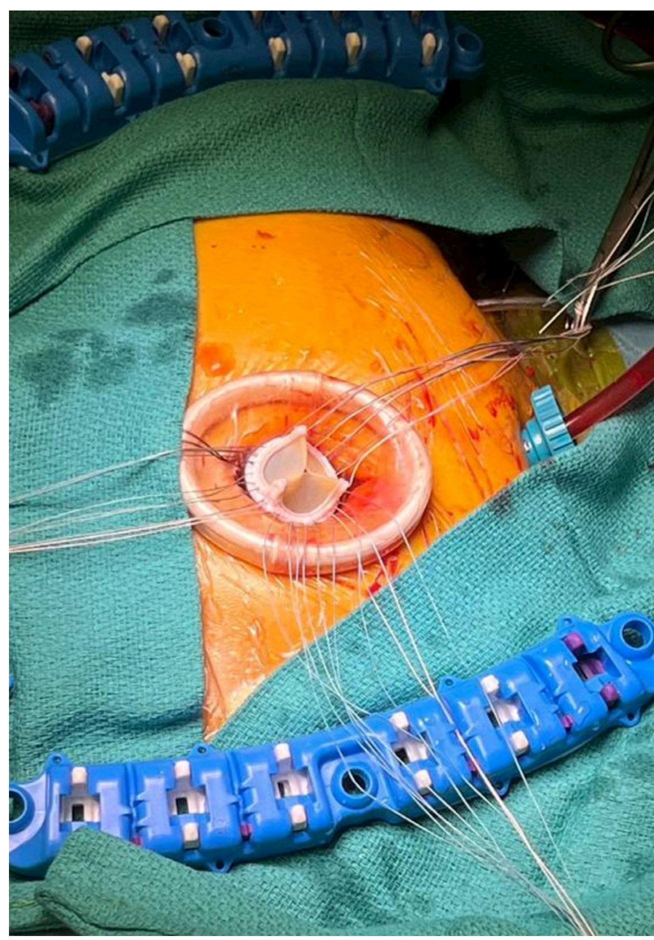

Figure 2 Implanting the valve prosthesis during ART access aortic valve replacement. The incision in the third intercostal space is demonstrated as well as the soft-tissue retractor. Surgical exposure during ART access. ART, anterior right thoracotomy.

Cannulation and cross-clamping

Unlike UHS, peripheral cannulation is necessary rather than optional. Usually via a Seldinger technique, the common femoral artery is cannulated, and its tip is positioned within the external iliac artery, thus avoiding iliac obstruction. To allow antegrade perfusion around the cannula to the distal limb, no tourniquets or clamps are placed on the femoral artery. The concomitant use of transoesophageal echocardiography to ensure correct placement of the venous cannula is strongly recommended.

Cross-clamps for aortic occlusion are usually selected to be low profile, such as the Cygnet clamp (Vitalitec, Plymouth, Massachusetts, USA) or V. Mueller Cosgrove Flex (CareFusion, San Diego, California, USA). This is usually introduced through a separate stab incision on the precordium.[33] The Chitwood clamp is also used in many tertiary centres, including the curved type and a recently updated straight variety.

The technical details of aortotomy, prosthetic valve implantation and aortotomy closure are identical to the UHS approach.

Endoscopic mini-AVR

The use of a thoracoscope in ART AVR allows better visualisation of the valve leaflets, annulus[34] and the right coronary ostium.[35] Although this reduces the space for suturing, an automated suturing device can circumvent this challenge.[36] In addition, the placement of three retraction stitches at the lowest part of the aortic valve commissures, as well as stitches to open up the aortic wall can help prevent the thoracoscope from occluding the view.[37]

Knot-tying

The use of a knot pusher or an automated knotting device may be beneficial, particularly for the right coronary cusp and for the generally deeper aortic annulus.[38] Moreover, Bouchot *et al*[39] noted that automated knotting devices can reduce AoX time.

Hand tying is of course possible, although certain adaptations in surgical procedure may be needed to facilitate this, including: (1) the use of numerous pericardial stay sutures to the skin edges, decreasing anteroposterior distance and; (2) pushing of the AoV towards the right through 'continuous positive end-expiratory pressure of the left lung' during cardiopulmonary bypass (CPB).

Automated knot-tying device

Automated devices (such as the Cor-Knot System (LSI Solutions, New York, USA)) have been shown to improve efficacy and facilitate aortic annulus suturing.[36 40 41] This can reduce technical challenges of knot-tying in restricted spaces, in addition to mitigating variations in complex patient anatomy and reducing both AoX and CPB times.[40]

Sutureless or rapid deployment valves

RDV augment MIAVR procedures by reducing operative times compared with conventional valves and eliminating the need for suturing/tying.[16] When comparing RDV versus conventional sutured valves via the same ART approach, Gilmanov *et al*[42] found significant reduction in operative times: CPB times were reduced by 30 min when using a RDV (p<0.0001) and AoX times decreased by 32 min (p<0.0001). Assisted ventilation times were also found to be shorter in the RDV group (p=0.001).

In addition, RDV has been used in MIAVR with minimal effects of a learning curve[43] or without the effects of the learning curve altogether.[12 24] Prosthesis misalignment and mild residual regurgitation were often accepted. However, the implementation of more rigid protocols have reduced the occurrence of such outcomes[43] and informed the learning curve with RDV more appropriately.

IMPLEMENTING THE INITIAL CASES

Early engagement with hospitals and patients

Prior to the implementation of the programme, hospital governance committee approval is necessary. The application process usually involves providing a description of the procedure, possible clinical indications, evidence-based data, expected procedural data at your hospital and support from both performing colleagues and other surgical colleagues. Furthermore, the involvement of a proctor with significant experience associated with the novel procedure should be stated.[25]

Written material to inform patients of alteration in the surgical technique and its benefits is vital: patients will feel more involved in the decision-making process.[44] Continuous quality improvement through regular audits will be of significant importance, thus improving outcomes.

The overall health economic cost benefit due to enhanced patient recovery can also be emphasised, thus justifying the initial costs incurred by training the surgical team.

Selecting the initial cases

Patient selection within the initial stages of the learning curve is vital (Box 1). It is important to note that patient safety is above all else when offering this type of surgery. As such, patients should be offered the gold standard sternotomy approach as a viable and safe alternative until it is certain that minimal harm will arise from performing the ART approach safely.

It is suggested that the initial period consist of 45–50 cases in patients lacking significant comorbidities, although in actual practice these are the patients who would benefit the most (table 2). In addition to avoiding patients with procedural contraindications, initial cases should also avoid the following classes of patients:

- Age >75.
- Morbidly obese.
- Current smokers.

Box 1 Summary of recommendations for aortic valve replacement via the anterior right thoracotomy approach

Patient selection
1. Patients with clear indication for isolated surgical AVR may be considered for MIAVR via ART with comparable outcomes to MS.
2. Patients who have had previous cardiac surgery and require intervention on the aortic valve can be considered for MIAVR via the ART approach.
3. In the initial stages of implementing ART AVR, low-risk patients should be selected who have a lower risk of complications (younger patients, non-smokers, low BMI).
4. Preoperative cross-sectional CT imaging in the initial stages should be recommended for all cases to ensure ease of access to the aortic valve and select the intercostal space for approach

Cardiopulmonary bypass
5. Aortic cross clamping should be performed with a low-profile clamp.
6. Femoral arterial or direct aortic cannulation are both acceptable strategies to institute CPB.
7. The use of TOE guidance for arterial and venous cannula positioning during the institution of CPB is highly recommended.

Staff/governance
8. The use of simulation with the surgical team prior to conducting the first live case of AVR via ART is highly recommended.
9. The implementation of a 'dry run' in the operating room using the relevant equipment and staff is recommended.
10. Regular audit of initial ART cases at the centre, followed by subsequent ART cases, is highly recommended.

ART, anterior right thoracotomy; AS, aortic stenosis; AVR, aortic valve replacement; BMI, body mass index; CPB, cardiopulmonary bypass; MIAVR, minimally invasive AVR; MS, median sternotomy; TOE, transoesophageal echocardiography.

Table 2 Indications for the use of ART and the contraindications

Indications	Contraindications
Established indication for surgical aortic valve replacement	
Low-risk patients: age <70, Euroscore <3%	High risk: EuroSCORE >5, age >75 Morbidly obese Current smokers
Favourable anatomy on CT: >50% of ascending aorta to right of sternum, aorta <16 cm away from chest wall	Unfavourable CT anatomy: ascending aorta >16 cm away from chest wall
Favourable surface anatomy: slim patient, accessible intercostal spaces	Unfavourable surface anatomy: obese patients
	Severe peripheral vascular disease (precluding the use of distal cannulation should this be required)

Please note these are not absolute contraindications. Patients would be assessed on a case-by-case basis. ART would be offered to patients based on overall feasibility for surgery and the expertise of the surgeon.
ART, anterior right thoracotomy.

- Severe peripheral vascular disease (precluding the use of distal cannulation should this be required).
- High-risk patients' with EuroSCORE>5.

Overenthusiasm in the initial cases should be avoided and patience should be exerted until lower-risk cases with the above-mentioned criteria become available.

Preoperative imaging

Presurgical cross-sectional imaging, commonly via CT facilitates preoperative planning in two ways (Box1) (figure 3):

1. Location of the aortic valve: The optimum location of the aorta and aortic valve have been described by many as key in determining operability and thus patient selection. Specifically, the left-right aortic location: if more than one-half of the ascending aorta is positioned to the right of a vertical line drawn from the right sternal border to the ascending aorta in the axial CT view, ART is appropriate.[3] Additionally, the distance from the proposed ART incision to the aortic annular plane should not exceed 16 cm.[45]
2. Detailed valve analysis: Clinicians have the ability to predict size of surgical valve based on annulus size. Calcium scoring is extremely useful, particular in bicuspid valves, in order to predict the difficulty in removing the native valve. This is critical in centres with early experience.
3. Location of right atrial appendage: Specifically, its proximity to the preferred intercostal which should be used for access. The space closest to the tip of the right atrial appendage is usually selected for access.
4. Peripheral vessels: Assessing vessel calibre and overall suitability for cannulation (both femoral and subclavian) helps avoid any unexpected difficulties intraoperatively and allows clinicians to plan for alternative access if needed.

Equipment needs

AVR via ART will require the introduction of novel instruments into the conventional cardiac operating theatre. This may include the thoracoscope, soft-tissue retractor, long-shafted equipment, automated suturing device and knot pusher. It has been suggested that comfort with the use of such equipment prior to the first case will allow the surgeon to focus on procedural aspects during the initial stages of the learning curve.[46] As such, it can be recommended that surgical teams handle and gain confidence with such equipment during conventional AVR through MS.

Trainees and surgical assistants

Surgeons and team leaders possess a vital role as educators and teachers: with the responsibility to train junior colleagues to high standards, thus enabling them to lead and subsequently train others in the following years. In a study by Soppa *et al*,[47] MIAVR was performed by junior trainees under direct supervision of a training surgeon without compromising patient safety or causing

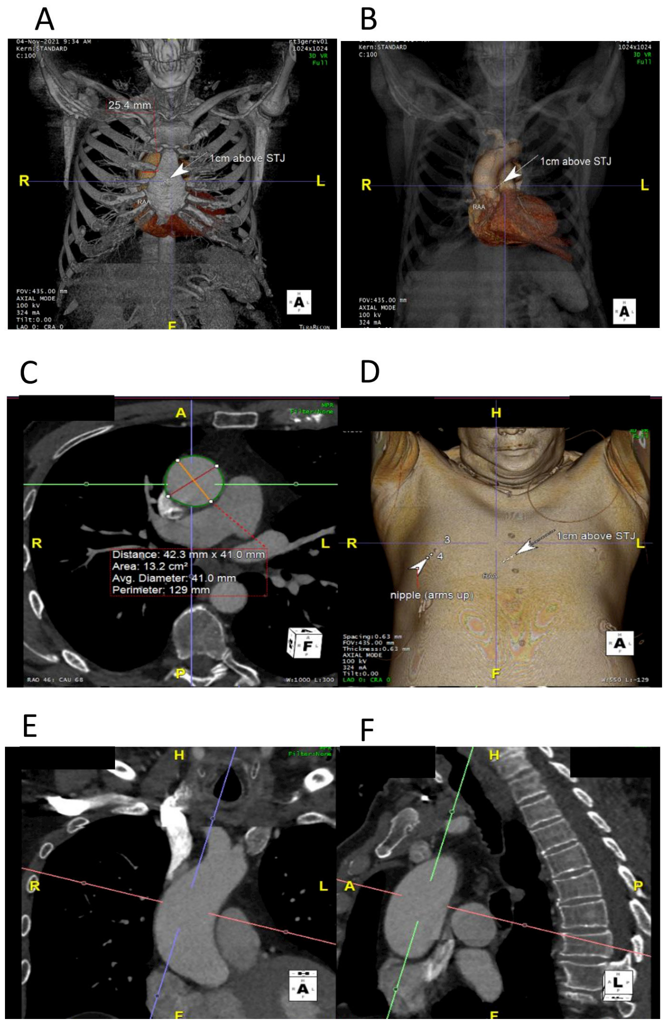

Figure 3 CT images with reconstruction of preoperative assessment for patient undergoing ART AVR (from top left to right): (A) Three-dimensional (3D) reconstruction showing location of ascending aorta to the right of the sternum. (B) 3D reconstruction of the great vessels and myocardium within the thorax, having removed the sternum and ribs anteriorly. (C) Axial image at the level of the mid-ascending aorta providing cross-sectional dimensions: area, diameter and perimeter. (D) Reconstructed surface anatomy of the patients thorax highlighting the third and fourth rib spaces and location of the ascending aorta. (E) Coronal CT image of the ascending aorta and root. (F) Sagittal image of the ascending aorta highlighting its distance from the planned ART incision. ART, anterior right thoracotomy; AVR, aortic valve replacement.

significant adverse complications. Furthermore, when using more complex procedures such as endoscopic MIAVR, the use of the thoracoscope enables an enhanced educational experience for the whole team, allowing trainees and assistants to comprehensively envisage the procedure and appreciate changes in visual perception.[34] Virtual reality training can significantly aid in shortening and smoothening the learning curve in its initial stages, improving patient safety, clinical outcomes and patient satisfaction.[48]

Staff considerations

Since novel surgeries bring new challenges to a department, it is of vital importance that all team members are actively encouraged to ask questions and voice potential concerns.[25] Safe intraoperative care and teamwork is dependent on effective dialogue during preoperative preparation,[49] including the surgeon, anaesthetist, perfusionist, scrub team and nurses (Box 1). Locally devised procedure specific checklists for the ART approach will help prevent errors and optimise outcomes, as evidenced by the WHO Surgical Safety Checklist.[34] The initial production of these checklists can be formed from experience in simulation training, and be updated and improved as required. This will also enable review of the team's performance and promote open conversations to improve teamwork and communication.[50]

POSTOPERATIVE CARE

First 24 hours

Either complete or near complete rewarming of the patient should be achieved while in the operating room. To allow for early extubation, moderating the dosages of opioid-based analgesia, sedatives and muscle relaxants is needed. Dexmedetomidine, a sedative that causes no respiratory depression and spinal anaesthesia are useful adjuncts.[38] Continuous local delivery of topical anaesthetic agents is are also beneficial. After ART, incision pain peaks early—within the first 12–24 hours; however, with limited rib retraction it subsides rapidly.

Appropriate chest tube and pacing wire management are important. Epicardial pacing wires are placed while the heart is still decompressed on CPB. A single basal chest drain passed through the skin antero-laterally via the seventh or eighth intercostal space towards the end of the case is usually adequate. Chest tubes are usually removed on the first postoperative day. Mobilising the patient before tube removal helps promote complete drainage from the costophrenic recesses, and very rarely should pleural taps or Seldinger drains be performed. Pacing wires are removed from the third postoperative day onwards, once the team is satisfied that normal sinus rhythm is restored.

Adverse events: general

Adverse outcomes should be clearly documented, with operative specifics and clinical outcomes. Moreover, serious adverse events should be reported to the training surgeon as soon as possible in accordance with safety reporting procedures, whereby adverse events can be classified and dealt with accordingly to ensure patient safety.

Adverse events: bleeding

In the event of significant bleeding or tamponade, re-exploration should be initially attempted through the ART incision. However, early in the centre's experience, a sternal saw should be readily available if required.

Debriefs should foster an open environment whereby there is no 'blame culture' and outcomes are understood to be a result of the team's efforts. Mentoring surgeons with further experience should be consulted as necessary in order to provide the team with an understanding of complications. Moreover, refinements in surgical technique over time and experience during the learning curve may additionally reduce the incidence of adverse events.[19]

Adverse events: groin seroma

Groin seromas are recognised complications of all surgery involving femoral vascular access.[51] Rarely, these become associated with deeper infections. Clinicians should have a low threshold for follow-up imaging of groin swelling: the majority of seromas will resolve spontaneously with conversative management. In ART surgery, less than 5% of patients develop groin seromas that require intervention.[52]

Adverse events: non-union of third rib

Another rare complication, although important to look out for, is rib non-union, which can occur in 1% of patients. This may result in persistent chest-wall discomfort, thus warranting intervention. As a recognised treatment in chest wall reconstruction, bone-grafting and/or mesh placement in the third rib space can be offered with good outcomes.

CONCLUSION

This consensus statement based on expert opinion and available evidence has attempted to provide an outline of factors to be considered in the introduction of a safe and effective ART AVR programme within the UK healthcare setting. Lack of randomised controlled data in this regard is a limitation but provides future directions for researchers. The aim of this statement is to provide evidence and guidance to encourage the dissemination and implementation of the ART approach to AVR, in order to improve patient safety, improved outcomes and satisfaction.

Twitter Joseph Zacharias @mrjzacharias

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ORCID iDs

M Yousuf Salmasi http://orcid.org/0000-0002-4085-1294
Massimo Caputo http://orcid.org/0000-0001-7508-0891
Joseph Zacharias http://orcid.org/0000-0003-1832-0638

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