

Minimally Invasive Surgical Aortic Valve Replacement: the RALT approach

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May 19, 2020

Abstract

Less invasive techniques for cardiothoracic surgical procedures are designed to limit surgical trauma, but technical requirements and preoperative planning are more demanding than those for conventional sternotomy. Patient selection, interdisciplinary collaboration, and surgical skills are key factors for procedural success. Aortic valve replacement is frequently performed through an upper hemisternotomy, but the right anterior minithoracotomy represents an even less traumatic, technical advancement. Preoperative assessment of the ascending aorta in relation to the sternum is mandatory to select patients and the intercostal access site. This description of the surgical technique focuses on the specific procedural details including the obligatory planning with computed tomography, and our cannulation strategy. We also sought to define the anatomical ascending aorto-sternal relationship, as it is of utmost importance in preoperative computed tomographic planning.

Key Words

Minimally Invasive Surgical Aortic Valve Replacement, Right Anterior Minithoracotomy, RALT, Minimally Invasive Cardiac Surgery, Minimally Invasive, Cardiac Surgery, Surgical Aortic Valve Replacement, SAVR, Aortic Valve Stenosis

INTRODUCTION

Minimally invasive aortic valve replacement (MIAVR) was first described by Cosgrove and Sabik in 1996¹. MIAVR is increasingly accepted in the surgical community with outcomes equivalent or superior to those of conventional AVR². In addition to the smaller incision and improved cosmetic result, numerous studies report a reduction in post-operative bleeding, transfusion requirements, rates of atrial fibrillation, length of mechanical ventilation, length of intensive care unit (ICU) and hospital stay, as well as post-operative pain with no difference in mortality^{3,4,5}. Furthermore, the right anterolateral minithoracotomy (RALT), with complete preservation of the sternum, has been proposed as an even less invasive approach for MIAVR⁶. Surgical aortic valve replacement (SAVR) has been shown to improve symptoms and survival, yet older patients are at an increased risk of morbidity and mortality, making a less invasive treatment strategy desirable in such patients⁷. Studies have shown that up to 40% of patients over the age of 70 are denied aortic valve surgery based on age and higher risk profiles^{8,9}. However, surgical MIAVR has been shown to reduce morbidity and decrease mortality in high-risk populations^{1,7,10,11}. Here, we describe our approach to MIAVR by way of RALT. We also aim to define and classify the preoperative anatomical ascending

aorto-sternal relationship as it is decisive in preoperative planning. We provide information about additional technical features and procedures that we have found to facilitate this challenging surgical procedure.

MATERIALS AND METHODS

Patient selection and preoperative planning

Patients who are eligible for SAVR, according to the 2017 ESC/EACTS guidelines for the management of valvular heart disease¹², need to be thoroughly evaluated regarding their suitability for the RALT approach. Reported exclusion criteria for SAVR-RALT are: aneurysmal dilatation of the ascending aorta, ascending aorta located completely retrosternal or relatively left lateral, pathological calcification of the ascending aorta (soft plaques) or prior cardiac surgery, history of right-sided pleuritis or a deep chest^{13,14,15}. In a preoperative computed tomography (CT) scan with contrast enhancement we evaluate the anatomical relationship between intercostal spaces (ICS), sternum, ascending aorta and aortic valve (Figure 1). Regarding anatomical suitability, we find the distance between the planned RALT incision and the aortic annular plane to be of great importance. Using 3D CT reconstructions of the patient's thoracic cage, we can predict precisely which ICS we should enter to achieve optimal exposure. We propose a *minithoracotomy to aortic annular plane* - distance not exceeding 16cm. Additionally, we analyse the anatomic ascending aorto-sternal relationship as summarized in Figure 2. We consider patients with type Ia and type Ib configurations suitable for SAVR-RALT. Aligning with previously published criteria¹⁵, type II and type III ascending aorto-sternal configurations would be defined as unsuitable for SAVR-RALT. Nevertheless, we have been able to show an intraoperative rightward shift of the ascending aorta by application of single left lung (SLL) positive-end-expiratory-pressure (PEEP) ventilation of 20 mmHg, thereby improving exposure and facilitating aortic cross-clamping (see below). Accordingly, patients with a preoperative type II configuration, hence classified as unsuitable, can be converted to a type Ib configuration and thus become suitable for SAVR-RALT (Figure 3).

Operative Technique

Patient positioning and anaesthetics.

The patient is intubated with a single lumen or double lumen endotracheal tube (in case of planned SLL-PEEP) and placed in supine position after induction of general anaesthesia. Defibrillator pads are placed on the chest wall. A transesophageal echocardiography (TEE) probe is placed and a thorough echocardiographic evaluation is performed.

Cannulation and CPB: percutaneous femoral cannulation.

Cardiopulmonary bypass (CPB) is established by percutaneous cannulation of the left common femoral artery and the right common femoral vein (single venous cannula (self-expanding smart cannula®), LLC, Lausanne, Switzerland)). The cannulas are placed in the SVC and femoral artery under TEE guidance. For arterial cannulation, two suture-mediated closure systems (Perclose ProGlide®, Abbott Vascular, Clonmel, Tipperary, Ireland) is placed before insertion of the cannula. If 3D CT reconstructions of the femoral vessels indicate the right groin as more suitable for cannulation, the right femoral artery is selected as arterial puncture site, as shown in figure 4. In general, a 16-, or 18-FR arterial cannula is sufficient depending on patient size and arterial diameter.

If peripheral vascular disease is suspected at the time of femoral cannulation or grade 4 or 5 atherosclerotic disease is evident by TEE, axillary artery cannulation for antegrade arterial perfusion. Venous drainage is augmented with vacuum assistance (-20 to -35 mmHg) to decompress the right heart. After establishment of CPB, a vent is inserted through the right superior pulmonary vein. Body temperature is maintained at around 34 °C. We use goal-directed-perfusion with DO₂-guided perfusion which is helpful in regard to optimal venous drainage as it allows you to safely reduce the pump-flow to 70-80% of the calculated flow if required.

Thoracotomy and incisional.

A small 4-5 cm right anterolateral minithoracotomy is used to enter the thorax through the 2nd or 3rd ICS (3rd ICS most common). A soft-tissue retractor and an intercostal rib spreader provide additional exposure. We do not perform rib-transection/resection. The right internal mammary and vein are left untouched.

Intrathoracic exposure.

The pericardium is opened over the aorta and the incision extended down towards the inferior vena cava. Carefully planned placement of pericardial stay sutures is key to obtain adequate exposure of the aorta and valve. The sutures are brought out by a suture hook through a stab incision one or two ICS above the thoracotomy (Figure 5). If the ascending aorta is located directly under or on the left side of the sternum, a PEEP of 20mmHg can be applied to the left lung only, inducing a rightward shift of the ascending aorta. This would be performed right before cross-clamping to enhance aortic exposure and facilitate positioning of the aortic clamp.

Video-assisted endoscopic monitoring.

After entering the thorax, a high-definition standard 30°-thoracoscope is placed into the chest via a 5mm port through the 2nd ICS at the right anterior axillary line. It not only provides an additional view from which to perform subsequent work but also brightly illuminates the entire chest. Throughout the procedure, the surgical field is flooded with CO₂ (2l/min) through this port.

Aortic cross-clamping and cardioplegia.

The trans-thoracic external aortic cross-clamp is inserted via the third ICS at the right midaxillary line. Antegrade cardioplegia is delivered directly into the aortic root through a long needle or selectively into the coronary ostia and repeated if necessary.

Aortic valve exposure and aortic valve replacement.

The aortic valve is accessed through a hockey-stick aortotomy incision. To enhance exposure, both sides of the aortotomy are retracted anteriorly and laterally with stay sutures. Valve resection and annular debridement are carried out under direct vision. All procedures are performed with specially designed long-shafted instruments. Additionally, a standard aortic wall retractor is used by the assistant to optimize visualization of the annulus. Sizing and suture placement are performed in standard fashion. After delivering the prosthesis onto the annulus, all annular valve sutures are tied utilizing the MiniCor-Knot® (LSI Solutions, Victor, NY) automated fastener device.

De-airing and closing.

Epicardial pacing wires are placed while the heart is still decompressed on CPB. Under TEE control, de-airing is performed antegradely via the aortotomy and retrogradely via vent-suction without direct manipulation of the heart. Separation from CPB, decannulation, TEE assessment of prosthesis function, and reversal of anticoagulation are all conducted as in conventional AVR. A standard chest tube is placed in the posterior pleural space. The pericardium is partially closed to limit adhesions of the lung to the heart for future interventions. A large pericostal suture is placed in a figure of eight fashion to approximate the ribs. The RALT incision is closed in routine fashion.

CONCLUSIONS

There are several implications for surgical practice:

- The surgical learning curve and the greater complexity of the procedure should be taken into account in the planning. This, however, should not deter cardiac surgeons from providing advanced minimally invasive techniques to patients.
- The advantages of SAVR-RALT can be combined with accelerated mobilization, improved chest wall stability and good cosmetic results.

- The RALT approach allows the sternum and ribs to be preserved in their entity. A sternum-sparing procedure decreases the potential of bleeding as well as the need for transfusions with the associated complications.
- Optimal patient preparation and correct surgical steps in the execution are significant factors for the success of this alternative access.

Acknowledgements and potential competing interests

The authors have no potential conflicts of interest relevant to this article.

Authors' contributions

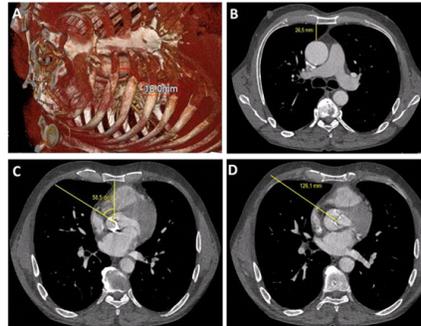
All authors made contributions to the development of the described methods, contributed important intellectual content, and reviewed and approved the final version of the manuscript.

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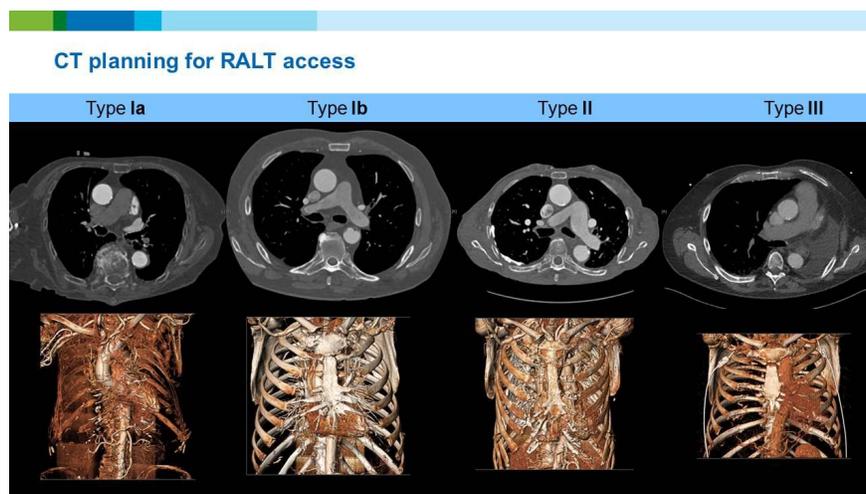
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Figure 1. Preoperative imaging and procedural planning are crucial in MIAVR-RALT.



A) 3D CT reconstruction (via *Aquarius iNtuition Viewer (TeraRecon)* software) for precise planning of the surgical strategy. **B)** Type Ib preoperative ascending aorto-sternal relationship: distance from ascending aorta to sternum is 2.65 cm. **C)** α -angle is 58.5°. **D)** Planned incision to aortic annular plane distance: 12.61cm.

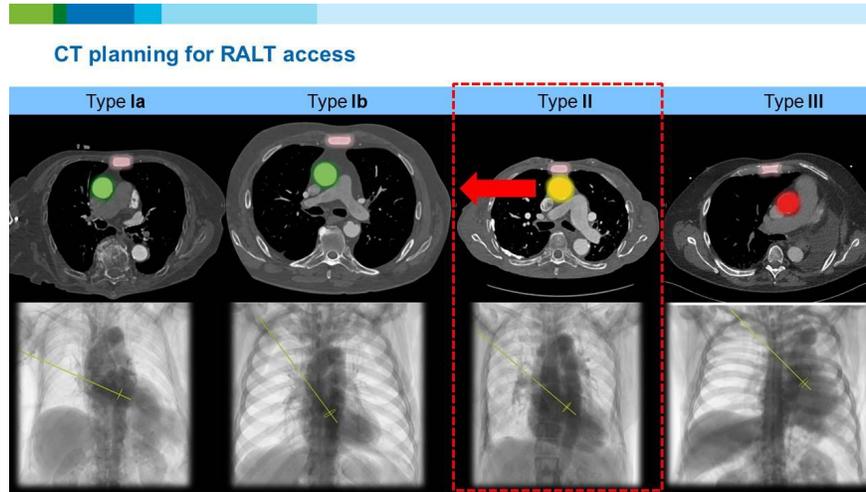
Figure 2. CT planning for RALT access: preoperative ascending aorto-sternal relationship.



Four types of ascending aorto-sternal relationships at the level of the main pulmonary artery:

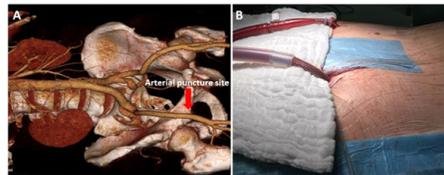
Type Ia: ascending aorta is completely rightward from the sternum; **Type Ib:** ascending aorta more than 50% located on the right side of the sternum; **Type II:** >50% of the ascending aorta underneath the sternum; **Type III:** ascending aorta more than 50% located on the left of the sternum.

Figure 3. CT planning for RALT access: preoperative ascending aorto-sternal relationship.



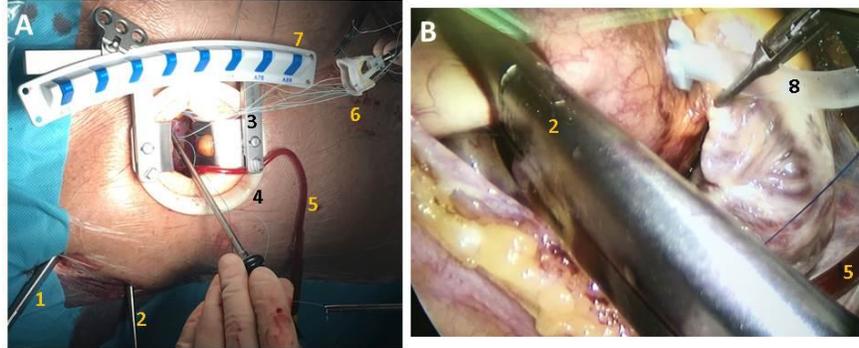
Theoretically, application of 20mmHg SLL-PEEP ventilation can shift the ascending aorta rightward to convert an anatomically unsuitable configuration into a suitable one. (red arrow).

Figure 4. Femoral cannulation for CPB: preoperative planning of the femoral access site and percutaneous cannulation.



A) 3D CT reconstruction of the femoral vessels: the femoral bifurcation is more cranial on the left than on the right side. The right common femoral artery therefore is the preferred arterial puncture platform for CPB. **B)** Percutaneous cannulation for CPB: right femoral artery for retrograde arterial perfusion and left femoral vein for venous drainage.

Figure 5. “The Berlin Setup” for minimally invasive surgical aortic valve replacement through a right anterior minithoracotomy.

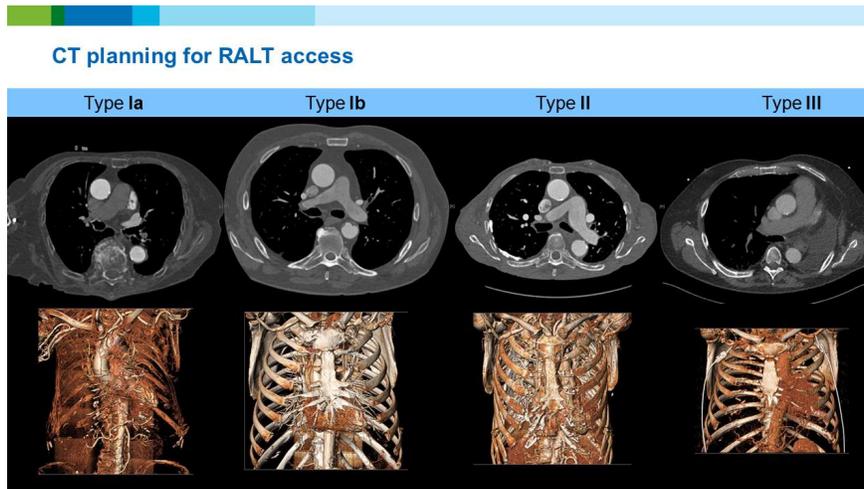


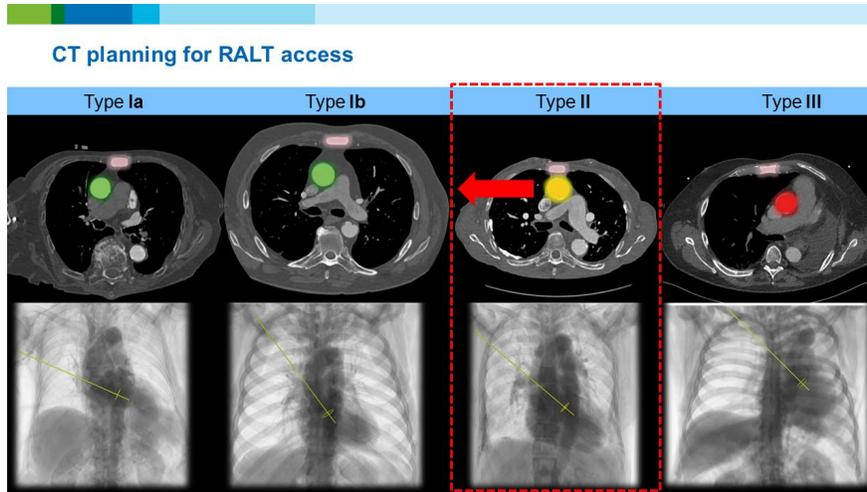
A) The surgeon’s perspective: right anterior minithoracotomy: 1= high-definition standard 30°-thoracoscope; 2=trans-thoracic external aortic cross-clamp; 3=rib spreader; 4=soft-tissue retractor; 5=left ventricular vent; 6=bioprosthetic aortic valve; 7=suture organizer.

B) Intraoperative endoscopic screenshot from the high-definition standard 30°-thoracoscope: 2= transthoracic cross-clamp; 5= left ventricular vent; 8=cardioplegia line.

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Figure 1_preop CT und 3D reconstruction.pptx available at <https://authorea.com/users/323922/articles/452353-minimally-invasive-surgical-aortic-valve-replacement-the-ralt-approach>





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Figure 4_Arterial puncture site_alternative route.pptx available at <https://authorea.com/users/323922/articles/452353-minimally-invasive-surgical-aortic-valve-replacement-the-ralt-approach>

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Figure 5_Intraoperative pictures.pptx available at <https://authorea.com/users/323922/articles/452353-minimally-invasive-surgical-aortic-valve-replacement-the-ralt-approach>