Chapter

Minimally Invasive Aortic Valve Surgery

Anze Djordjevic and Igor Knez

Abstract

Minimally invasive aortic valve surgery by definition means performing procedures through alternative approaches without the need to divide the sternum completely. Even though this contributes towards lowering the mortality and morbidity of patients, minimally invasive techniques have to be tailored to the unique patient as well as surgeon characteristics. With the advancements made in invasive cardiology techniques, the line between invasive cardiology and minimally invasive cardiac surgery is becoming thinner and thinner. We are presenting state-of-the-art techniques and outcomes for surgical aortic valve replacement via upper mini-sternotomy or anterior right mini-thoracotomy. In addition, aortic valve repair and valve-sparing procedures through a minimally invasive approach are discussed.

Keywords: aortic valve, valve surgery, minimally invasive surgery, upper mini-sternotomy, right anterior mini-thoracotomy

1. Introduction

Modern and complex aortic valve surgery is dependent on extracorporeal circulation established first in 1953 by Gibbon [1]. The first, Hufnagel's aortic valve was implanted in the descending aorta in 1956 [2] and from then on annual numbers of aortic valve procedures performed through a full median sternotomy have risen significantly over the next decades. In 2002, Cribier performed the first transcatheter aortic valve implantation (TAVI), which paved the way for percutaneously resolving patients with prohibitive surgical risk [3]. Although, first minimally invasive approaches were developed a decade earlier, they gained increased interest after ever looser indications for TAVI. That dictated a response from the cardiac surgery society. Cosgrove performed the first minimally invasive aortic valve replacement (AVR) through a right parasternal approach back in 1996 [4]. In the same decade, more minimally invasive approaches were developed, such as upper mini-sternotomy, anterior right mini-thoracotomy (ART) or transverse sternotomy. Today, most isolated AVRs are performed through either upper mini-sternotomy or ART (**Figure 1**) with reduced pain, improved respiratory function, early recovery and an overall reduction in trauma.

Regardless of the approach, some essentials must not be compromised in aortic valve surgery. These include safe application of a stable aortic cross-clamp, adequate visualization of the aortic valve, ensuring the same degree of myocardial protection as in median sternotomy, enabled approach to the aortic root and ascending aorta, and ability to quickly convert to median sternotomy if needed.

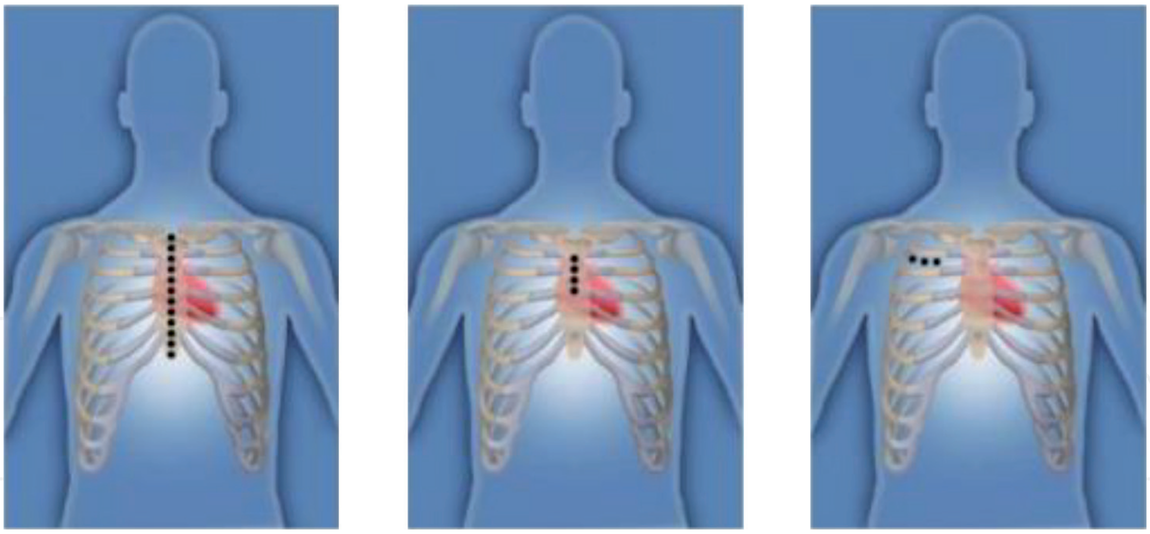

Figure 1.
Different approaches for aortic valve surgery. Left: median sternotomy; middle: upper mini-sternotomy; right: anterior right mini-thoracotomy.

The present chapter aims to describe the two most commonly used minimally invasive approaches to aortic valve surgery (upper mini-sternotomy and ART) with a special focus on surgical technique and outcomes.

2. Upper mini-sternotomy

Skin incision runs over the upper half of the sternum and is usually <10 cm long. Sternotomy can be performed with either the standard (our preference) or oscillating saw and is performed in a "J" matter into the right 3rd (Maribor preference) or 4th (Graz preference) intercostal space. The selected intercostal space is determined by the total sternal length, method of myocardial protection delivery (antegrade or combined ante−/retrograde cardioplegia) and surgeon preference. If exposure of the aortic valve is not satisfying, the "J" mini-sternotomy can be modified to a "T" mini-sternotomy or converted to a full median sternotomy. However, care must be taken during sternotomy osteosynthesis when more than two sternal fragments are present to avoid excessive postoperative bleeding or sternal dehiscence. In upper "J" mini-sternotomy, prophylactic division of the right internal thoracic artery (RITA) is not required.

A small-blade retractor is inserted and the pericardium is opened in a longitudinal matter (**Figure 2**) [5]. Two to three stay sutures on both sides are applied and the intrapericardial contents are lifted upwards. Care must be taken not to reduce cardiac preload, which could lead to patient deterioration in the presence of severe aortic valve stenosis.

The cardiopulmonary bypass could be established centrally or peripherally. At our institutions, central cannulation remains the preferred option except in cases of severe ascending aortic calcifications. After systemic heparinization with 300 I.U./kg to achieve an activated clotting time (ACT) > 480 s, the distal ascending aorta is cannulated through two Prolene 3-0 purse-string sutures with pledgets placed in a circular fashion. A double-stage venous cannula is placed through a single Prolene 3-0 purse-string suture either through the right atrial appendage (Graz preference) or in the superior vena cava (Maribor preference). When cannulating the right atrial appendage, the venous cannula could be positioned to the side of the mini-sternotomy wound or under the undivided sternum and beneath the xiphoid (**Figure 3**) [6].

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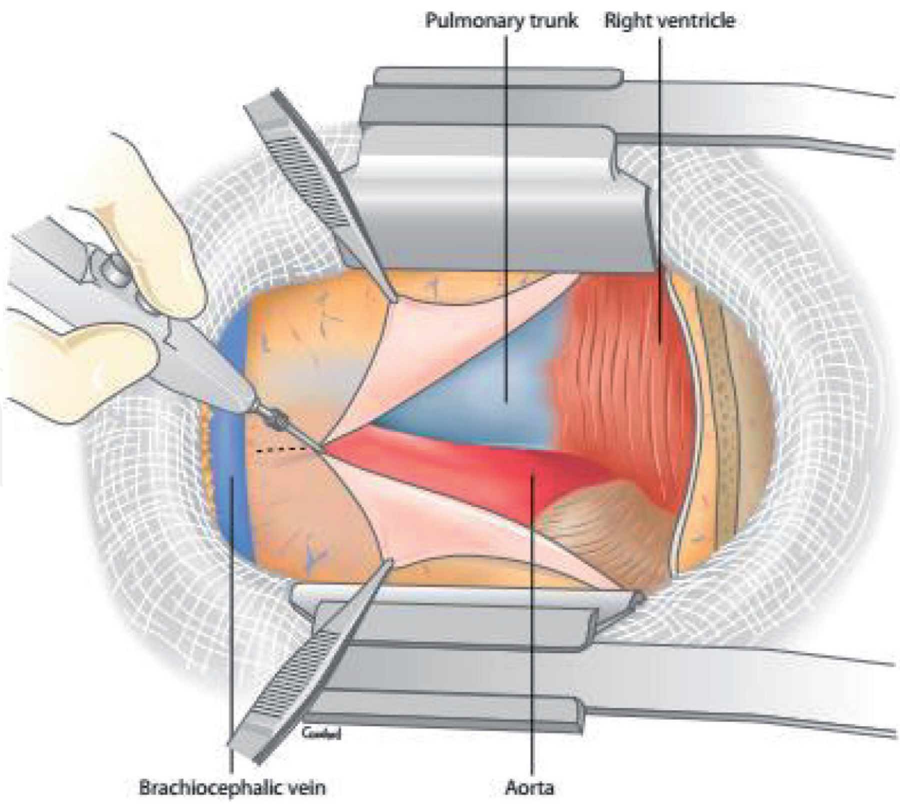

Figure 2.
Incision of the pericardium through an upper mini-sternotomy [5].

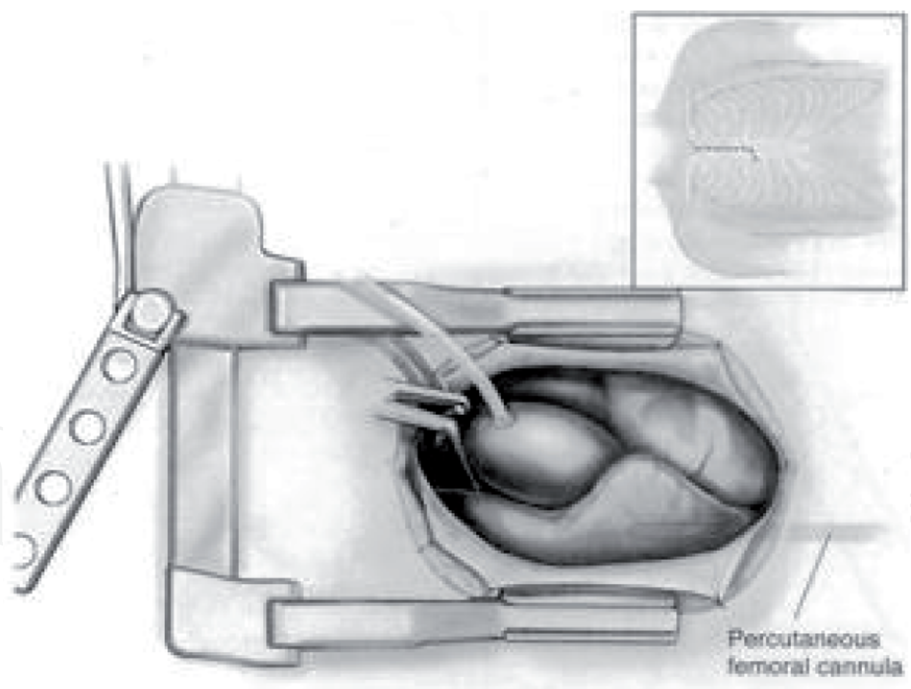

Figure 3.
Upper mini-sternotomy. Operative field and sternal incision [6].

The choice of cardioplegia dictates the type of cannulation. Some cardioplegic solutions (for example del Nido extracellular crystalloid cardioplegia) require only antegrade delivery. On the other hand, other solutions (such as blood cardioplegia or St. Thomas extracellular crystalloid cardioplegia) enhance myocardial protection when administered via both ante- and retrograde fashion. In that case, the retrograde cardioplegic cannula is inserted in the coronary sinus through a single Prolene 3-0 U-suture placed between the venous cannula and the inferior vena cava. The antegrade cardioplegic cannula is inserted in the proximal ascending aorta through a single Prolene 3-0 U-suture.

After placing the patient on cardiopulmonary bypass, a left ventricular vent is placed through the right superior pulmonary vein or directly through the aorta. Patients could be safely operated on in normothermia (Maribor preference) or mild hypothermia (34°C) (Graz preference).

The aorta is cross-clamped, cardioplegia is administered and the intrapericardial sac is flushed with cold saline to topically cool the heart. An oblique semicircular incision is made into the ascending aorta and three stay sutures are applied to each commissure (**Figure 4**) [5].

The aortic valve is excised with a 2-mm margin-left on the aortic annulus. After flushing the left ventricular outflow tract (LVOT) and ascending aorta to remove residual calcified particles, an appropriate artificial valve sizer is introduced. Interrupted Ticron 2-0 U-sutures with pledgets are placed through the annulus with pledgets on the ventricular side. Care must be taken on the commissure between the right and a coronary leaflets not to injure the AV node. When an appropriate valve size is chosen, these sutures are placed on the sewing ring and the valve is lowered into the aortic annulus. The sutures are tied either by hand or by novel artificial tying devices (e.g., Cor-Knot). Coronary ostia are carefully inspected to prevent catastrophic consequences (**Figure 5**).

The aortotomy is closed using two Prolene 4-0 running sutures, both starting at the aortotomy edges. The patient is rewarmed if needed and the heart is de-aired mostly through a needle incision in the ascending aorta, just distal to the aortotomy. After removing the aortic cross-clamp, a rhythm check is required. If ventricular fibrillation, external defibrillation is applied. When sinus rhythm occurs, an epicardial temporary pacemaker wire is placed on the right ventricle. This maneuver is facilitated when the heart is actively emptied through the venous cannula and the wire is then pulled out through the 3rd right intercostal space.

Also, during active venous drainage, the external drains are placed. Usually, one retrosternal drain is sufficient placed either through the subxiphoid area or

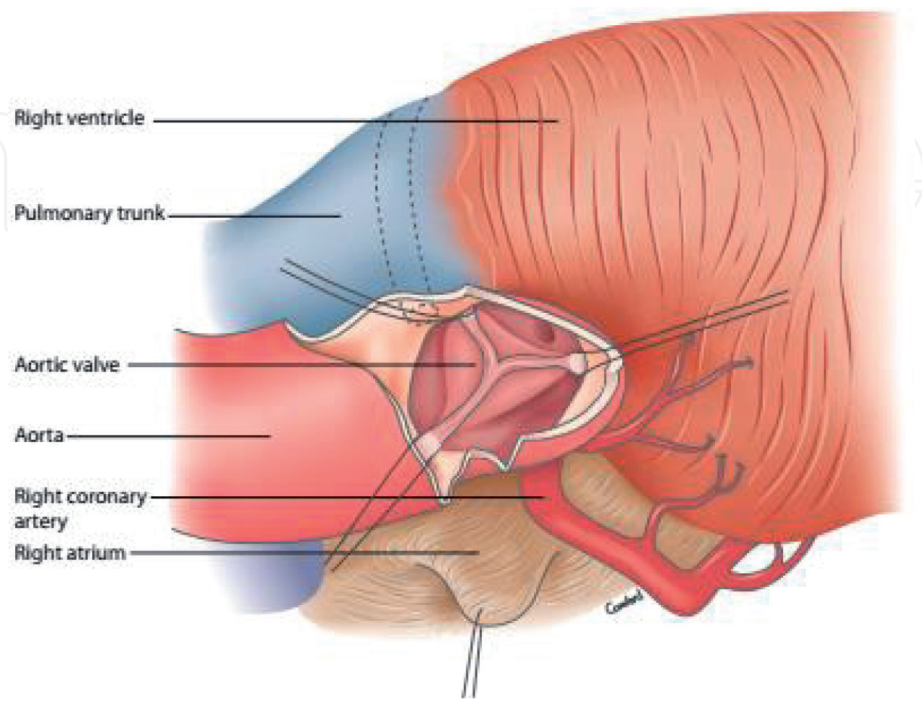

Figure 4.
Superior view of the aortic valve [5].

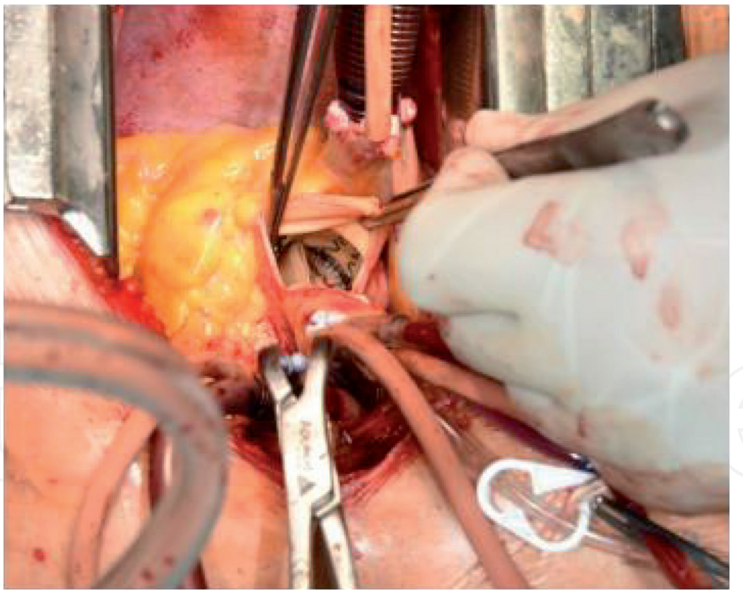

Figure 5.
Probing the coronary ostia (courtesy of Medical University of Graz).

the 3rd right intercostal space lateral to the RITA. Another viable option is also placement of transpleural drainage tubes.

Weaning from cardiopulmonary bypass follows after complete reperfusion with step-by-step decannulation and oversewing all cannulated spots with Prolene 5-0. Simultaneously with aortic decannulation, protamine is administered in a 1:1 ratio to reverse the effects of heparine. With the pericardium left open, sternal osteosynthesis is performed with one obliquely placed wire between the non-divided lower sternum and the 2nd right intercostal space and one figure-of-eight placed wire around the manubrio-sternal joint. Finally, fascia, subcutaneous tissue and skin are sutured, respectively.

3. Anterior right mini-thoracotomy

To consider this approach, a preoperative chest computed tomography (CT) scan is mandatory to assess the relationship of intrathoracic structures, especially the distance of the aortic root to the right-sided rib cage. The main criteria are: (1) the position of more than half of the ascending aorta is over the pulmonary artery on the right side of the sternum and (2) the distance of the ascending aorta from the sternum is <10 cm [7, 8]. Over the 2nd right intercostal space, a <10 cm long incision is made with the medial portion at the sternal edge. The intercostal muscles are sharply divided using electrocautery. Upon entering the thoracic cavity, the superior right pulmonary lobe is retracted using selective bilateral lung intubation and prophylactic division of the RITA is necessary to prevent extensive blood loss. A small-blade retractor is inserted and the pericardium is opened in a longitudinal matter (**Figure 6**) [5]. It is of paramount importance to identify the phrenic nerve before pericardial incision to avoid postoperative delayed mechanical ventilation due to respiratory disturbances. Two stay sutures on both sides are applied and the intrapericardial contents are lifted upwards. We advise against routine rib resection. In most ART cases, visualization is already satisfactory after intercostal muscles' division.

The cardiopulmonary bypass could be established centrally or peripherally. At our institutions, central cannulation remains the preferred option. The rest of the operation commences in a similar fashion as previously described in the chapter on upper mini-sternotomy [9, 10].

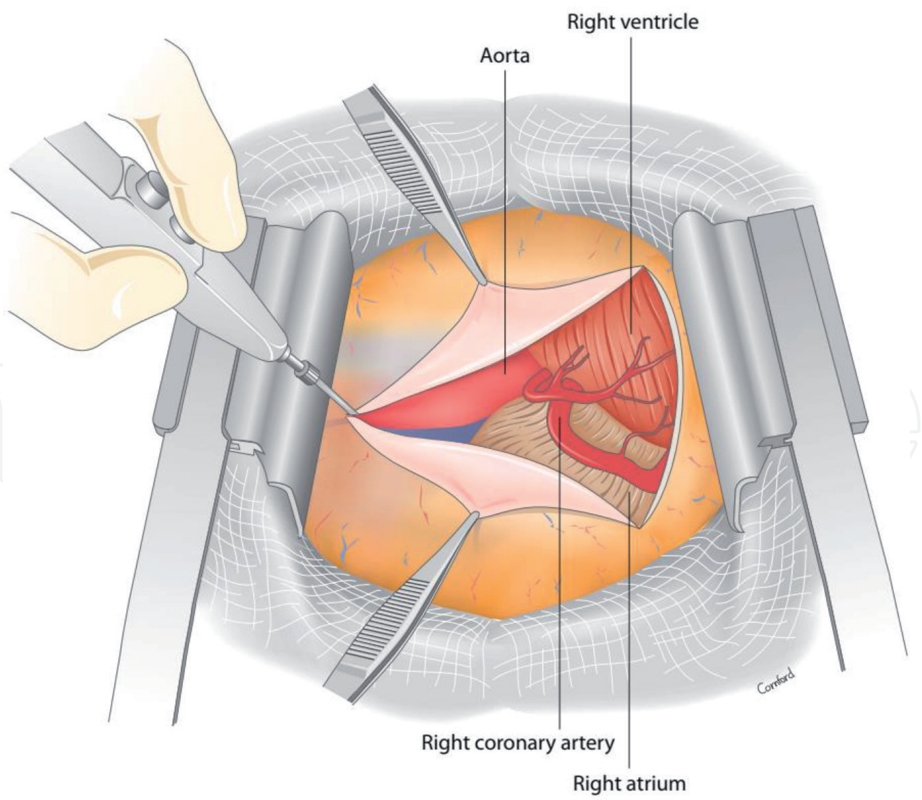

Figure 6.
Pericardial incision through an anterior right mini-thoracotomy [5].

4. Outcomes

Both already described minimally invasive approaches to the aortic valve were developed in the 1990s. The Cleveland group developed the upper mini-sternotomy technique in 1996 [4] and the first published data on the ART are from New Delhi group from 1993 [9].

The first large published article regarding minimally invasive aortic valve surgery was written by the Boston group. They reported their experience with 526 consecutive minimally invasive aortic valve procedures, which were mostly done through an upper mini-sternotomy (93%). Their publication has shown excellent results with short- and long-term mortality at 2% and 5%, respectively. Freedom from reoperation at 6 years was 99% [6].

Encouraged by these data, the number of minimally invasive aortic valve surgery have risen significantly in the following years. A report was recently published on the clinical trends between median sternotomy and minimally invasive approaches for aortic valve stenosis in three high volume aortic valve surgery centres in the USA (Houston, Atlanta, and Miami). In the observed three-year period, the overall number of AVRs increased by 107% owing to improved diagnostics and TAVIs for previously denied patients. Minimally invasive AVRs increased by 57% and median sternotomy AVRs decreased by 15% [11].

Outcomes of minimally invasive aortic valve surgery are similar or even superior in some reports to those of conventional median sternotomy surgery [12].

4.1 Mortality

Mortality rates are similar when comparing ART [13–15] or upper mini-sternotomy [6, 16, 17] with median sternotomy, respectively. One-year survival is reported to be >95%, whereas 5-year survival ranges from 80–95%, respectively.

4.2 Postoperative bleeding

The incidence of re-exploration due to excessive bleeding ranges from 3.8% up to 12% [15–18]. The latter high number was reported by Semsroth et al. in a subgroup of 167 patients who were operated through an ART. One explanation could be that they already experienced lots of issues with intraoperative bleeding, which resulted in the fact that bleeding was the predominant cause for conversion to median sternotomy [18]. Most often significant bleeding occurs on the aortotomy edges, on cannulation sites, especially the right superior pulmonary vein, on sternotomy edges or if the RITA is injured.

4.3 Transfusion

Blood product transfusion is reported to be significantly lower in minimally invasive aortic valve surgery compared to traditional median sternotomy. Reported incidences are from 21.3% to 48.8% [13–18]. The highest reported incidence was by Stolinski et al. in a series of 211 patients who undergone an ART, which is still significantly lower than in the median sternotomy group (67.3%, $p < 0.001$) [15].

4.4 Postoperative atrial fibrillation

Rhythm disturbances often accompany cardiac valvular procedures. The reported incidences of postoperative atrial fibrillation (POAF) are from 12.8% to 32.2% [13, 15–17].

4.5 Mechanical ventilation

Mechanical ventilation is significantly shorter in patients undergoing minimally invasive aortic valve surgery (5 vs. 6 h; $p = 0.04$) [17] and only 4.3% required prolonged ventilation >24 h [16].

4.6 Intensive care unit and hospital stay

Intensive care unit (ICU) and hospital length of stay are perhaps the most evident advantages of minimally invasive aortic valve surgery. Both parameters are shorter in comparison to median sternotomy aortic valve surgery [15]. Semsroth et al. reported a mean duration of ICU to stay 22 h for upper mini-sternotomy and 21 h for ART patients [18]. Although, Ghanta et al. reported longer ICU stays, early discharge defined by discharge by the 4th postoperative day (POD) was achieved in 15.8% in the minimally invasive group compared to only 4.2% in the median sternotomy group ($p < 0.01$) [17]. About 52.8% of minimally invasive surgery patients are discharged by the 6th POD and only 7.9% have a prolonged stay over 12 days [16].

4.7 Acute kidney injury

Acute kidney injury (AKI) incidence ranges from 1% to 4.7% [16, 17] with hemodialysis from 0.5% to 13.2% [15, 18]. The large differences are a consequence of different AKI definitions and acquired protocols for renal replacement therapy. The highest reported incidence of hemodialysis comes from the report by Semsroth et al. Their explanation lies in the necessity of a preoperative CT imaging for patients receiving minimally invasive aortic valve surgery through ART, as contrast enhancement is nephrotoxic and might increase the risk for AKI [18].

However, a word of caution is proper. Not all patients are suitable for minimally invasive approaches, especially for ART which is technically more demanding. The reported exclusion criteria for ART are concomitant ascending aortic aneurysms, 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, a deep chest or women with large breasts [10, 19]. On the other hand, this approach is highly beneficial for disabled patients on crutches or those with deformed sternum due to radiation or injury.

5. Aortic valve repair and valve-sparing procedures through a minimally invasive approach

All of the information on minimally invasive approaches so far have been regarding AVR. In recent years, some authors have published their experience with performing aortic valve repair or aortic valve-sparing procedures through minimally invasive approaches.

The Beijing group reported their results in upper mini-sternotomy aortic root surgery. A relatively small sample of 18 patients was matched with an equally large median sternotomy group. There were no differences in the categories of surgery, as aortic root surgery was combined with ascending aorta replacement or aortic arch replacement. Aortic cross-clamp was significantly longer in the minimally invasive group. Regarding postoperative outcomes, fewer transfusions, lower drainage volume, shorter mechanical ventilation time as well as shorter ICU and hospital stay were observed [20].

The ART approach was tested for the treatment of ascending aortic pathology. The Houston group compared 74 patients who operated through an ART with 103 patients with median sternotomy. In a matched cohort, a trend towards longer aortic cross-clamp time as well as significantly higher numbers of the bicuspid aortic valves in the ART group was observed. Again, fewer transfusions, shorter ventilation time, shorter ICU and hospital stay were experienced. Interestingly, short-term mortality was similar between the two groups [21].

A systematic review of the results of the minimally invasive aortic root, ascending aorta or aortic arch performed by the Bristol group revealed similar mortality, decreased length of cardiopulmonary bypass, shorter ICU and hospital stay, fewer reoperations due to bleeding and lower incidence of postoperative AKI in the minimally invasive group. A major limitation of this review is very low-quality non-randomized evidence [22].

The Warsaw group reported their experience with 167 upper mini-sternotomy aortic root or ascending aorta operations. About 49% undergone ascending aortic replacement, 26% a combination of ascending aortic and aortic valve replacement and 25% one of the aortic valve-sparing procedure (reimplantation/remodeling). Short- and long-term mortality was 1% and 5%, respectively. Seven % reoperations for bleeding, 1.7% prolonged ICU stays and 4.8% postoperative AKIs were observed [23].

6. Pitfalls in minimally invasive surgery

As already mentioned in the text above, there are some specific pitfalls encountered in minimally invasive aortic valve surgery. Let us summarize and emphasize the most frequently seen:

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- injury to the RITA (prophylactic division is recommended in ART, sharp tissue division and electrocautery use should prevent RITA injury in upper mini-sternotomy),

- poor exposure (excision of the prepericardial fatty tissue),

- difficult ascending aortic cannulation (always be prepared for peripheral cannulation, most often through the femoral artery),

- difficult de-airing (using a gauze-covered long instrument and additional CO_2 inflation during the procedure can help aid against air embolisms),

- reoperation (we strongly advocate against using minimally invasive approaches for redo surgery),

- do not jeopardize the patient's safety—if severe difficulties occur during a minimally invasive approach, do not hesitate to convert it into full median sternotomy.

7. Conclusions

Minimally invasive aortic valve surgery carries substantial benefits to patients with aortic valve disease. Fewer transfusions, shorter ICU and hospital stay, shorter mechanical ventilation alongside similar survival, POAF and AKI incidence are the main advantages when compared to conventional median sternotomy. The cardiac surgery society should aim at providing additional training to all cardiac surgeons to implement minimally invasive approaches in the majority of patients. Only by doing so, the cardiac surgery society can offer a counter-balance to ever-increasing numbers of TAVI, which will undoubtedly spread also in moderate or even low-risk patients in the following years [24].

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Conflict of interest

The authors report no conflicts of interest.

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