

## Minimally invasive aortic valve replacement – pros and cons of keyhole aortic surgery

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### Abstract

Over the last twenty years, minimally invasive aortic valve replacement (MIAVR) has evolved into a safe, well-tolerated and efficient surgical treatment option for aortic valve disease. It has been shown to reduce postoperative morbidity, providing faster recovery and rehabilitation, shorter hospital stay and better cosmetic results compared with conventional surgery. A variety of minimally invasive accesses have been developed and utilized to date. This concise review demonstrates and discusses surgical techniques used in contemporary approaches to MIAVR and presents the most important results of MIAVR procedures.

**Key words:** aortic valve, ministernotomy, minimally invasive minithoracotomy.

### Introduction

Surgical aortic valve replacement (AVR) is the gold standard in treatment of severe aortic stenosis and remains a class I/B recommendation for symptomatic patients [1]. It was first performed by Harken and Starr in 1960 [2] through a full median sternotomy and has been successfully performed in thousands of patients since then. It has been proven as a safe, reproducible and highly effective procedure providing excellent long-term outcomes [3]. However, due to its invasive nature it remains associated with surgical access site complications such as wound infection and sternal dehiscence. Alternative techniques have been developed to help minimize sternal division, providing better thoracic stability and improved wound cosmetics. This concise review demonstrates and discusses surgical techniques used in contemporary ap-

### Streszczenie

Przez ostatnie 20 lat małoinwazyjna wymiana zastawki aortalnej (MIAVR) stała się bezpieczną, dobrze tolerowaną i skuteczną opcją leczenia chorób zastawki aortalnej. W porównaniu z tradycyjną sternotomią wykazano, że małoinwazyjna chirurgia zastawki aortalnej zmniejsza liczbę powikłań pooperacyjnych, zapewniając szybszą rehabilitację i powrót do zdrowia, krótszą hospitalizację jak również lepsze efekty kosmetyczne. Do chwili obecnej powstało wiele technik operacyjnych z małego dostępu. Poniższy artykuł przedstawia metody operacyjne oraz najbardziej istotne wyniki współczesnej małoinwazyjnej wymiany zastawki aortalnej.

**Słowa kluczowe:** zastawka aortalna, ministernotomia, mitorakotomia małoinwazyjna.

proaches to minimally invasive aortic valve repair and replacement (MIAVR).

The term “minimally invasive cardiac surgery” refers to “any procedure not performed with a full sternotomy or cardiopulmonary bypass (CPB) support” [4]. Therefore minimally invasive cardiac surgical procedures should not be defined in terms of a specific approach, but it constitutes a philosophy in surgical treatment which aims to reduce the degree of surgical invasiveness [5]. In contrast to off-pump techniques used in myocardial revascularization, valvular procedures are based mainly on surgical access, because CPB support cannot be escaped. In this regard the definition “minimally invasive” has been widely discussed as being invalid, and another term such as “minimal access” may be preferred.

It should be noted that an alternative technique should provide outcomes at least as good as the standard ap-

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proach without compromising safety and effectiveness of the procedure. Numerous studies presenting notable benefits of MIAVR have been published on the subject, proving that MIAVR has evolved into a safe, well-tolerated and efficient surgical treatment option.

### Intercostal accesses to the aortic valve

Among variations of minimally invasive approaches to aortic valve surgery, two main types can be identified: the first aiming at avoidance of full sternotomy and the second using intercostal access as an alternative approach.

**Right parasternal incision** (Fig. 1) – first introduced by Cosgrove and Sabik in 1996, started it all [6-8]. While it offered excellent access to the myocardium and its vessels, it promoted chest wall instability and deformation, as the technique was based on a 10 cm vertical incision right to the midline, extending from the second to the fifth costal cartilage with resection of the costae adjacent to the incision. Due to its limitations, Sabik's technique was rarely used and remains of historical significance only.

#### Advantages:

- complete sternal preservation,
- excellent myocardial and vascular exposure,
- combined procedures possible (+CABG, +MV/TV).

#### Drawbacks:

- chest wall stability difficult to obtain,
- RIMA ligation,
- detachment of the right pectoral muscle,
- conversion to full sternotomy disastrous.

**Trans-sternal incision** (Fig. 2) – first described by Cohn in 1997 [8] – represents an opposite approach, as the incision is not parallel, but perpendicular to the midline. An 8-10 cm skin incision is made at the level of the second or third intercostal space (ICS) with complete transverse sternal transection. This semi clam-shell approach provided exceptional visualization of the aorta, but it required liga-

tion of both internal thoracic arteries and was therefore quickly abandoned.

#### Advantages:

- excellent exposure of the aorta and pulmonary trunk,
- central cannulation feasible,
- mitral valve accessible via left atrial roof.

#### Drawbacks:

- both IMAs divided,
- both pleural spaces entered,
- high rate of postoperative bleeding,
- conversion to full sternotomy cumbersome.

**Right anterior minithoracotomy** (Fig. 3A, B) – first described by Benetti *et al.* in 1997 [9] – involves a small, 5 to 8 cm transverse incision in the second or third intercostal space. While technically demanding, it offers excellent cosmetic results and no sternal or costal injury. This approach is the second, after upper hemisternotomy, most frequently used. However, due to limited visualization, CT may be required to verify aortic anatomy.

#### Advantages:

- complete sternal preservation,
- mobility of upper limbs is preserved as the upper rim remains untouched,
- excellent cosmetic effect,
- best for Rapid Deployment and sutureless valves as well as transaortic transcatheter valves,
- conversion to full sternotomy feasible and safe,
- feasible in subjects with unfavorable arterial graft configurations (AVR after CABG) (Fig. 4).

#### Drawbacks:

- RIMA injury possible,
- possible complications after femoral cannulation,
- long learning curve,
- may require non-standard surgical instruments,
- may require CT prior to surgery to evaluate aortic anatomy.

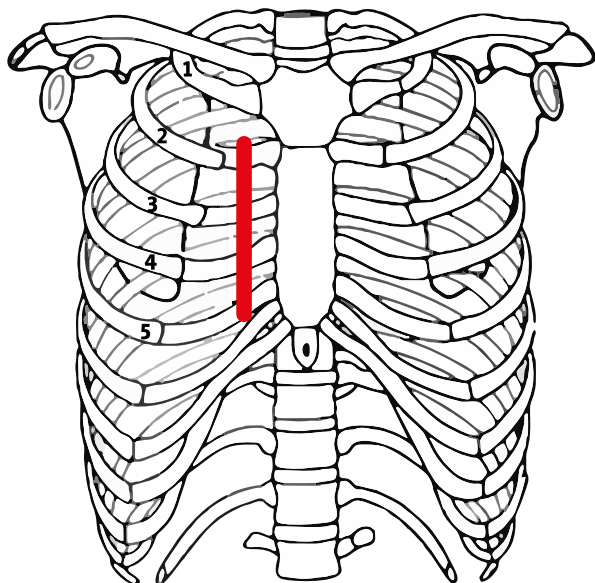


Fig. 1. Right parasternal incision

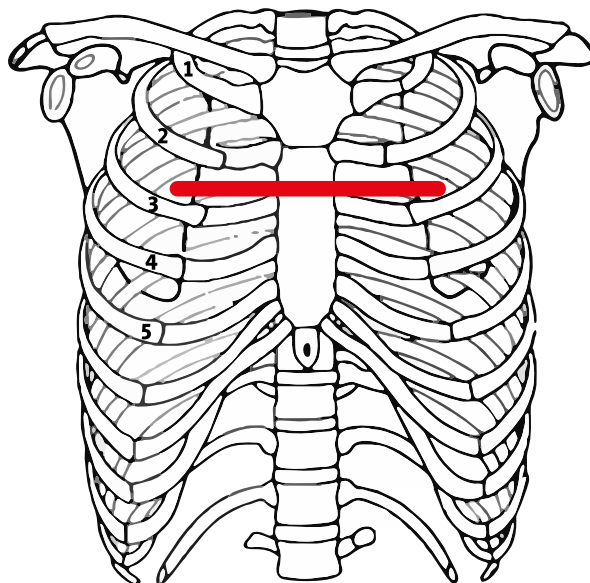


Fig. 2. Trans-sternal incision

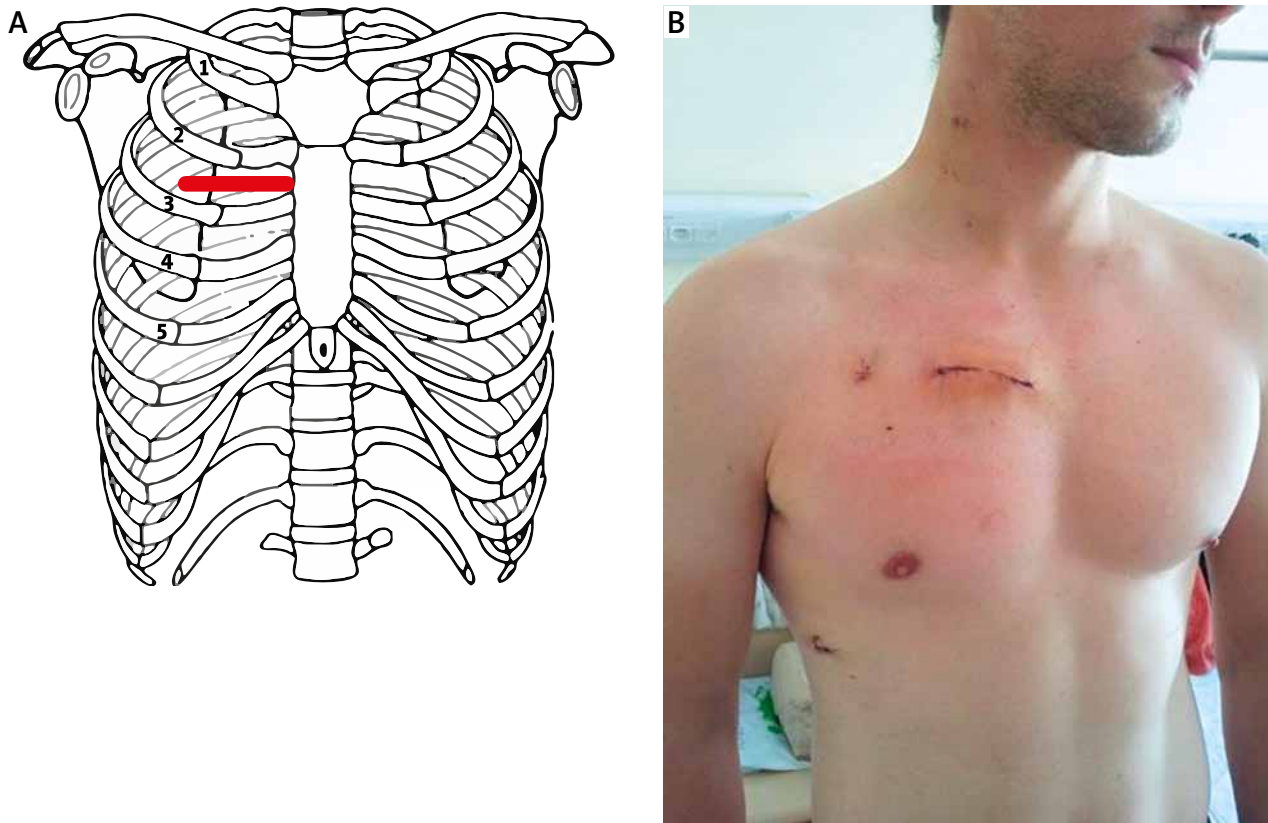


Fig. 3. A – Right anterior minithoracotomy. B – Right anterior minithoracotomy – photo

### Limited sternal division

Surgical access through hemisternotomy can be divided into three groups according to anatomical criteria. We can distinguish the **upper** (“inverted T-shape”, “V-shape”, “J-shape”), **middle** (“reversed C-shape”, “H-shape”) and **lower hemisternotomy** (“inverted L-shape”, “T-shape”).

Upper hemisternotomy, probably due to the similarities it shares with full sternotomy, has become most frequently chosen for MIAVR access. With various modifications it offers great flexibility and may be easily tailored to both patient and surgeon preferences.

Among a few approaches, two dominate:

**T- and J-shaped mini-sternotomy** (Fig. 5, 6). While T was proposed by Izzat *et al.* [10] in 1998 the J was first used by Konertz *et al.* [11] in 1996. The difference is almost indistinguishable, with slightly better exposure in the T, rather than J approach, and opposite when it comes to sternal stability.

In both cases the skin incision may be reduced even further – to a 4-5 cm or 6-8 cm incision made from the sternal notch to the second, third or fourth right intercostal space (Fig. 7).

#### Advantages:

- excellent exposure of the great vessels,
- no need for special setup or equipment,
- central cannulation of both lines (A and V),
- both IMAs preserved,
- easy conversion to median sternotomy,

- concomitant procedures (LAA ligation, root replacement, interpositional graft placement feasible, but difficult).

#### Drawbacks:

- limited/impossible retrograde cardioplegia administration,
- deairing cumbersome,
- caution regarding adequate placement of chest tube,
- the upper limb rim is not closed, so the mobility of the upper extremities is impaired after the operation.

Middle hemisternotomy represents a valuable alternative, but remains rarely used. Lower hemisternotomy,



Fig. 4. Right anterior minithoracotomy scar vs. full sternotomy scar

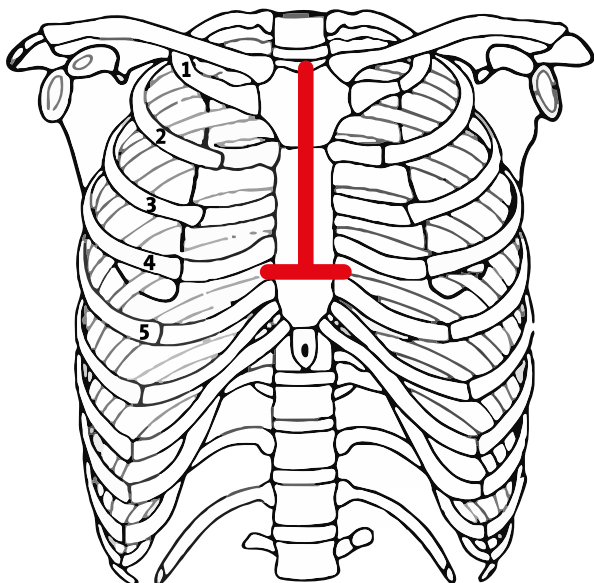


Fig. 5. T-shaped mini-sternotomy

however, provides excellent access to the heart and its vessels, enabling isolated and combined surgical procedures, including surgical revascularization. Moreover, central cannulation is feasible as well as myocardial protection via the

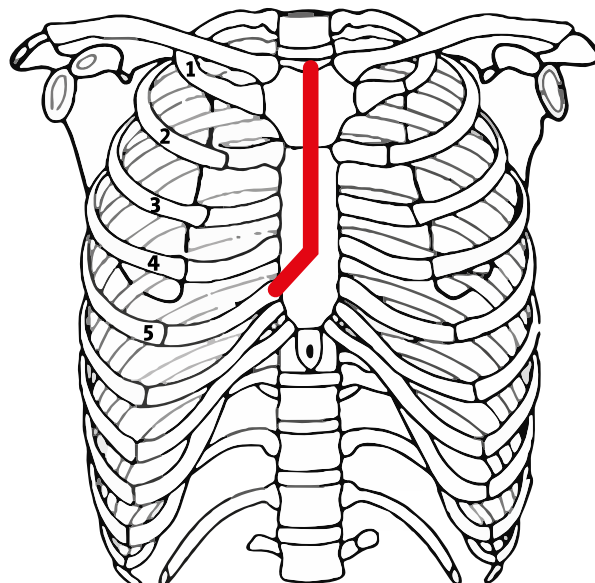


Fig. 6. J-shaped mini-sternotomy

coronary sinus. Stability of the rim of the upper limbs in the postoperative period is one of the key aspects of this procedure. Our results (in press) confirm its usefulness and good safety profile.



Fig. 7. Ministernotomy – photo

## Results

The results of MIAVR, especially in regard to the standard approach, can only be appreciated by means of small single center studies or registries. The lack of prospective, multicenter randomized clinical trials means there is no evidence-supported statement on either superiority or inferiority of MIAVR. Despite these limitations, MIAVR has been proven to be at least as safe and as effective as the standard approach, with some potential advantages other than cosmetic effects. Less surgical trauma, less postoperative bleeding and blood units transfused, faster recovery, shorter hospital stay and ICU stay, and less pain are considered important benefits of MIAVR over conventional sternotomy. On the other hand, the avoidance of full sternotomy makes the procedure more technically demanding, predisposing to failures, frequent in inexperienced hands.

### Conversion to full sternotomy

Conversion from the mini to full approach remains an important issue in terms of patient safety and procedural efficacy. It has been proven to be a relevant factor contributing to worse postoperative outcomes. The rate of conversion during MIAVR has been reported to be as low as 3% [12, 13]. While nearly half of them were elective and occurred prior to aortic clamping, because of inadequate exposure of the heart the others constituted an emergency due to intra- or postoperative difficulties such as bleeding, coronary sinus injury, left heart distention and ventricular fibrillation [14]. Noteworthy are reports with an incredibly high rate of conversion (14%), suggesting that a delayed decision to convert doubled operative time and may have

resulted in an increased rate of serious complications [15]. It seems, however, not to be the conversion itself that leads to these diminished outcomes, but complications caused by the difficult, minimally invasive approach or lack of surgical experience. It is clear that conversion from ministernotomy can be easily performed any time during the procedure. The drawback – fragmented half of the sternal bone – may be difficult to mend, especially if an inverted T sternal incision was made. The literature, however, lacks solid data on post-conversion sternal instability. On the other hand, sternotomy in cases of thoracic access is no different from the standard approach, except for the cosmetic result, as the patient is left with two thoracic incisions.

Therefore meticulous preoperative evaluation of patients who are scheduled to undergo the mini-invasive approach is necessary to prevent such events and to improve the effectiveness of this procedure.

### **Postoperative bleeding**

Reduction of post-operative bleeding and the need for blood transfusions are the two most commonly mentioned benefits of MIAVR. This finding has been reported frequently by independent centers. Dogan *et al.* in a prospective, randomized clinical trial analyzing 40 patients announced that post-operative chest tube output was significantly lower in MIAVR (240 vs. 495 ml,  $p = 0.008$ ) when compared to controls [16]. Another randomized clinical study by Bonacchi *et al.* showed that 37.5% (15/40) of MIAVR patients required postoperative transfusions compared with 62.5% (25/40) of conventional AVR [17]. Likewise, Glimanov *et al.*, comparing 182 patients who underwent AVR through either ministernotomy or minithoracotomy to the same group of patients with full sternotomy using propensity score analysis, reported a considerable reduction in blood product exposure for the mini-invasive access (39% vs. 68.2%,  $p = 0.009$ ) [18]. In contrast, Stamou *et al.* found no difference in transfusion requirements, although the small size of the analyzed population might have affected the results [19]. A meta-analysis conducted by Brown *et al.* which included 26 clinical studies (4586 patients) confirmed reduced blood loss in MIAVR patients within the first 24 h after the procedure (WMD – 79 ml, 95% CI: 23-136 ml) [12]. There is a perception that less surgical aggression driven by mini-invasive techniques accounts for a smaller amount of blood loss and may contribute to decreased mortality/morbidity associated with transfusions and bleeding explorations [20].

### **Postoperative recovery and rehabilitation**

A noteworthy and important issue considering the particularly important advantage of MIAVR is the potential for faster recovery. Better stability of the sternum and thorax, closing the rim of the upper limbs with mini-invasive techniques leading to improvement of the patient's respiratory function and earlier mobilization translates into shorter mechanical ventilation support, shorter ICU stay and overall hospital stay, and shorter time required for rehabilita-

tion. Numerous studies have demonstrated a statistically significant reduction in time spent in hospital for MIAVR patients [12, 21-25]. Murtuza *et al.* in their meta-analysis reported that ventilation time, ICU stay and total length of stay were significantly shorter with the mini-invasive group (9.4 vs. 12.5 h; 1.8 vs. 2.4 days; 8.8 vs. 10.2 days, respectively) [26]. Sharony *et al.* reviewed their MIAVR population and created two comparable propensity-matched cohorts, each of 233 patients. The median length of stay was shorter in the MIAVR group in comparison with patients who underwent AVR through full sternotomy (6 vs. 8 days,  $p = 0.001$ ). Furthermore, a greater percentage of minimally invasive patients than full sternotomy patients was discharged home rather than sent to rehabilitation facilities or nursing homes (65.7% vs. 52.9%,  $p = 0.05$ ) [27]. The most recently published study, by Khoshbin *et al.*, also revealed a remarkable benefit in this field. A meta-analysis of available randomized control trials has been conducted with the conclusion that the length of ICU stay was significantly shorter by 0.57 days in favor of the mini-sternotomy group (CI: –0.97 to –0.2,  $p = 0.003$ ) [28].

Among other aspects that can contribute to faster recovery, the postoperative pain felt by the patient is of great importance. Indeed, its intensity is sometimes problematic to estimate, because of the individual patient's threshold, although logically the minimally invasive approach should cause less pain and discomfort postoperatively. The smaller incision, the use of a rib retractor instead of a regular sternum spreader, and keeping most of mediastinal structures intact are likely reasons. Moreover, preserved chest stability facilitates subsequent respiratory and motor rehabilitation, making them more sufficient. Yamada *et al.* in a retrospective investigation found that mini-invasive patients had earlier recovery and improved quality of life with diminished pain medication administration compared with the conventional AVR population [29]. The prospective study published by Candaele *et al.* suggested that partial upper sternotomy improves pulmonary function and reduces pain in comparison with standard full sternotomy [30], whereas Machler *et al.* failed to find any benefits of MIAVR other than diminished pain medication administration in a prospective randomized study [31]. It is true that excessive stretching of the intercostal space or brachial plexus traction when the minithoracotomy approach is being performed may make this procedure more painful. In this regard, the upper partial sternotomy offers the comfort factor of sternotomy over parasternal thoracotomy [32]. Nevertheless, the surgeon's attitude and the way that he treats the incision remains the most important issue. In principle, if the wound is handled with care, the need of increased postoperative analgesic support will not arise.

### **Mortality**

The influence of less traumatic access on cardiac-related mortality has not yet been resolved. While most published data indicate similar intraoperative and early failure rates, there is increasing evidence on reduced early mortal-

ity in MIAVR patients. Doubtful as it may seem, the differences are probably due to the reduced need for blood products and faster recovery. However, this trend is limited to high-volume centers, which overcome the steep learning curve and technique-related complications. However, negative outcomes with newly adopted techniques often remain underreported, blurring the overall benefit of MIAVR.

In published studies (Table I), operative mortality was comparable to the conventional FS procedure [12, 14, 17, 33], justifying its safety and high feasibility rate with excellent outcomes [3].

### Wound complications. Cosmesis

Improved cosmetics remains the unquestionable benefit of MIAVR. Not only is the incision smaller, but it is also often located lower, allowing for uninhibited exposure of the upper chest. Apart from obvious comfort and mental relief (as it is perceived as a “lesser” procedure), it provides faster recovery and rehabilitation. Sternal wound infections (SWIs) have been reported in MIAVR as large comparative studies failed to reveal superiority of MIAVR in SWI prevention [12, 14]. Moreover, in the case of emergency conversion to full sternotomy, the risk of both SWI and sternal instability seems to increase due to more complex sternal incisions.

On the other hand, sternal dehiscence may not be present when upper minithoracotomy is performed. Although superficial wound infections have been reported [39], their incidence is minimal when compared to upper hemisternotomy [3, 33, 40]. This benefit becomes less evident in elderly patients, as they suffer from more comorbidities,

including more advanced diabetes and osteopathy. Noteworthy is the fact that femoral cannulation accompanying this technique creates an additional risk of wound complications. The occurrence of groin wound problems has been reported as between 1.7% and 15% [39]. On the other hand, ministernotomy was not associated with lower incidence of sternal wound infection.

### The future of MIAVR

Transcatheter aortic valve replacement (TAVR) has consistently been improved for the last 5 years, with the intent of refining outcomes in the high-risk patient population. The results of the PARTNER trial (Placement of Aortic Transcatheter valves) showed no difference between TAVI and conventional surgery in terms of early mortality and one-year survival in operable patients [41]. Assuming that longer CPB time associated with MIAVR might compromise the outcomes in fragile patients, the use of new sutureless devices should have reduced operative time, thus facilitating the mini-invasive procedure [42]. Perhaps MIAVR could be considered an alternative to TAVI for high-risk patients. On the other hand, there are many patients with concomitant coronary artery disease accompanying severe aortic stenosis in whom numerous serious comorbid conditions increase the risk of a standard operation. This population would have greater benefits of a hybrid procedure combining MIAVR and PCI, but our hypothesis needs further examination. Although numerous studies evaluating the impact of MIAVR on clinical outcomes have been published to date, there is a lack of true randomized, prospective large trials.

Tab. I. Minimal access vs. full sternotomy approach – early mortality comparison

Author	MIAVR pts (n)	Approach	Early mortality (%)	Comparison to SS pts	Reference/Study type
Tabata <i>et al.</i> [3]	1005	ministernotomy/parasternal incision	1.9 > 80 ys → 1.7	–	o
Johnston <i>et al.</i> [14]	832	J-incision	0.96	0.96 <i>p</i> NS	<i>c/r</i> adj
Mihaljevic <i>et al.</i> [34]	526	ministernotomy/parasternal incision	2.0	3.0 <i>p</i> NS	c
Soltesz and Cohn [35]	875	J-incision	2.0 > 80 ys → 1.9	–	o
Merk <i>et al.</i> [36]	477	J-incision	0.4	2.3 <i>p</i> 0.01	<i>c/r</i> adj
Furukawa <i>et al.</i> [37]	404	J-incision	1.0	1.0 <i>p</i> NS	<i>c/r</i> adj
Sharony <i>et al.</i> [27]	233	RT	5.6	7.3 <i>p</i> NS	<i>c/r</i> adj
Bakir <i>et al.</i> [13]	232	J-incision	2.6	4.4 <i>p</i> NS	c
Glauber <i>et al.</i> [38]	138	RT	0.7	0.7 <i>p</i> NS	<i>c/r</i> adj
Brown <i>et al.</i> [12]	2054	26 studies	OR 0.71; CI: 0.49-1.02 <i>p</i> NS	m	
Murtuza <i>et al.</i> [26]	2101	26 studies	OR 0.72; CI: 0.51-1.00 <i>p</i> 0.05	m	

o – observational, c – comparative, *r* adj – risk adjusted, m – metaanalysis, RT – right thoracotomy, SS – standard sternotomy, OR – odds ratio, CI – confidence interval, NS – non-significant

Only four RCTs with relatively small cohorts have appeared in the literature. Of note, almost the whole knowledge of perceived advantages derived from MIAVR has been based mainly on comparative investigations which might have compromised the results due to patient selection biases. Therefore, to clarify existing opinions and to establish the position of MIAVR in future valve surgery, large, properly designed RCTs also scrutinizing cost-effectiveness must be conducted.

Finally, it must be highlighted that the full sternotomy approach still remains the main technique in use for aortic valve replacement in most countries, giving satisfactory results. In accordance with the well-known maxim *salus aegroti suprema lex*, surgeons should use the approach that they are familiar with. Forcing a mini-invasive procedure at any cost may be dangerous in some cases.

## Dislosure

Authors report no conflict of interest.

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