

Manubrium-limited sternotomy decreases blood loss after aortic valve replacement surgery

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Abstract

OBJECTIVES: Minimally invasive surgical approaches for aortic valve replacement (AVR) are growing in popularity in an attempt to decrease morbidity from conventional surgery. We have adopted a technique that divides only the manubrium and spares the body of the sternum. We sought to determine whether patients benefit from this less-invasive approach.

METHODS: We retrospectively analysed our prospectively maintained database to review all isolated aortic valve replacements performed in an 18-month period from November 2011 to April 2013.

RESULTS: One hundred and ninety-one patients were identified, 98 underwent manubrium-limited sternotomy (Mini-AVR) and 93 had a conventional median sternotomy (AVR). The two groups were well matched for preoperative variables and risk (mean logistic EuroSCORE mini-AVR 7.15 vs AVR 6.55, $P = 0.47$). Mean cardiopulmonary bypass and aortic cross-clamp times were 10 and 6 min longer, respectively, in the mini-AVR group (mean values 88 vs 78 min, $P = 0.00040$, and 66 vs 60 min, $P = 0.0078$, respectively). Mini-AVR patients had significantly less postoperative blood loss, 332 vs 513 ml, $P = 0.00021$, and were less likely to require blood products (fresh-frozen plasma and platelets), 24 vs 36%, $P = 0.042$. Postoperative complications and length of stay were similar (discharge on or before Day 4; mini-AVR 15 vs AVR 8%, $P = 0.17$). Valve outcome (paravalvular leak mini-AVR 2 vs AVR 1%, $P = 1.00$) and survival (mini-AVR 99 vs AVR 97%, $P = 0.36$) were equal.

CONCLUSIONS: A manubrium-limited approach maintains outcomes achieved for aortic valve replacement by conventional sternotomy while significantly reducing postoperative blood loss and transfusion of blood products.

Keywords: Aortic • Valve disease • Minimally invasive surgery

INTRODUCTION

Isolated aortic valve replacement (AVR) is a safe and effective procedure with an in-hospital mortality rate of 1.49% and a 5-year survival rate of 83% in the UK [1]. Access via a full median sternotomy remains the standard approach to this operation, providing a good view with minimal postoperative pain and a low rate of wound complications (1–2%) [2].

However, there has been a drive across all surgical specialties to minimize operative trauma by reducing wound size via ‘minimally invasive techniques’. Smaller incisions potentially offer numerous postoperative benefits, the most tangible being improved cosmesis. However, for most patients, this remains a secondary consideration after a successful operative outcome has been ensured [3]. Hence, any technique with reduced operative access must, at the very least, demonstrate noninferiority in outcomes with the standard approach.

In cardiac surgery, ‘minimally invasive’ has been defined as ‘a small chest wall incision that does not include a full sternotomy’ [2]. Multiple techniques have been trialed, each with its own merits and

limitations. Two broad categories exist: those that continue to divide the sternum (but only partially) and those where alternative access is gained (e.g. through a minithoracotomy or parasternal incision).

Most techniques that gain access via a midline incision still divide a significant portion of the sternum (up to 3–4 intercostal spaces). At our institution, we have employed a manubrium-limited incision to the second intercostal space, which produces a smaller scar while ensuring that the ‘body’ of the sternum remains intact and stable. This technique utilizes the minimum-required working space to perform AVR [4]. We sought to examine whether a manubrium-limited technique (mini-AVR) provides effective and comparable results to a full median sternotomy (AVR).

MATERIALS AND METHODS

Data collection

We retrospectively analysed our cardiac, echocardiography and transfusion databases as well as cross-referencing with the medical

notes, intensive care charts, discharge summaries and clinic correspondence. Our cardiac database is a comprehensive in-patient log of pre-, peri- and postoperative details collected for national audit requirements.

The study period ran for 18 months from the advent of our mini-AVR programme (November 2011 to April 2013). Inclusion criteria were all isolated aortic valve replacements in patients over 18 years of age. Exclusion criteria were any concomitant procedure, including root surgery, redo surgery and emergency surgery, and patients with endocarditis.

Operative technique

Our centre introduced manubrium-limited sternotomy (mini-AVR) in 2011. Two surgeons (Enoch Akowuah and Andrew Goodwin) trained in the technique and adopted this as their 'standard' practice. The remaining five surgeons performed aortic valve replacements via a conventional sternotomy (AVR). Referral pathways remained the same and the operation the patient received depended solely on the preferred technique of the consultant to whom they were referred; there was no preselection of patients. Seven (7%) of patients who were referred to the mini-AVR surgeons had a conventional sternotomy. Three of these were seen in the pre-operative clinic before the commencement of the programme. Two, early in the programme, opted for the conventional procedure. One could not have an intraoperative transoesophageal ECHO because of a recent gastrointestinal bleed and one was carried out as an emergency procedure.

For the mini-AVR, an incision was made from the sternal notch to the second intercostal space. The manubrium was divided longitudinally in the midline. The sternum was then transected in both directions from the second intercostal spaces until the midline incision was reached, creating a V-shape. This procedure is depicted in Fig. 1. Aortic cannulation was through the ascending aorta. Given that the right atrium is poorly visualized with this technique, venous cannulation was percutaneous through the femoral vein (Seldinger technique guided by transoesophageal ECHO). Suction was used as necessary to aid venous drainage. Antegrade cardioplegia was used for myocardial protection and venting was via the pulmonary artery. A transverse aortotomy was

performed, followed by standard aortic valve insertion using interrupted non-pledgeted braided sutures. The aortotomy was closed in a single layer. One pericardial drain and ventricular pacing wires were placed in all patients. Atrial wires were placed if needed. For mini-AVR, this has to be performed before removing the cross-clamp to facilitate the view of the right atrium and ventricle. Sternal closure was with two wires in the manubrium and two wires from the body of the sternum up to the manubrium.

For the conventional technique, a standard median sternotomy was performed. Cannulation was via the ascending aorta with two-stage right atrial cannulation for venous drainage. The technique for venting was at the surgeon's discretion (although 80% of cases were vented via the pulmonary vein). Antegrade cardioplegia was used for myocardial protection with 40% having additional retrograde cardioplegia). All valves were inserted using interrupted sutures. Both single- and double-layer techniques were used for aortotomy closure. Each of the five surgeons using the conventional approach performed less cases than their mini-AVR counterparts. However, they were all experienced surgeons in aortic valve replacement. Before the introduction of the mini-AVR programme, there were no differences in outcome between the seven surgeons, and it is unlikely that those performing the conventional procedure deskilled during the 18 months of this study.

Statistical analysis

The data were analysed on an 'intention to treat' basis using IBM SPSS v. 19.0 for Mac. For categorical variables, Fisher's exact test was performed. For continuous data, the Kolmogorov-Smirnov test was used to verify whether the data were normally distributed. Where a normal distribution could be proved, Student's *t*-test was used; otherwise, we performed a Mann-Whitney *U*-test. Statistical significance was defined as a *P*-value of <0.05.

RESULTS

One hundred and ninety-one aortic valve replacements were performed. Ninety-eight (51%) of these were by mini-AVR. Of these,

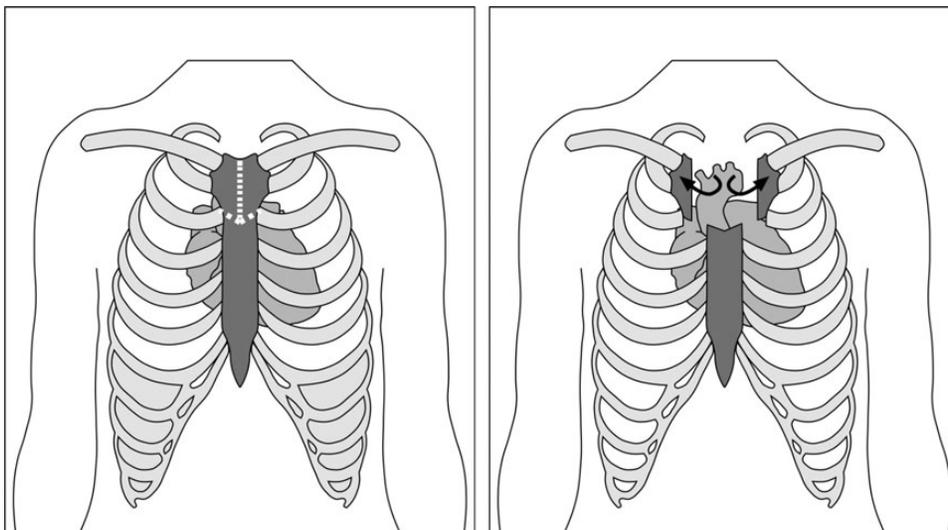


Figure 1: Manubrium-limited sternotomy.

eight patients were converted to a full sternotomy intraoperatively, but have been analysed in the mini-AVR group.

Preoperative factors

The demographic profile and preoperative risk factors are shown in Table 1; the two groups were well matched. For calculated risk, there was no statistical difference in the logistic EuroSCOREs between the two groups (Mini-AVR 7.15 and AVR 6.55, $P = 0.47$). Patients with high-risk EuroSCOREs: >10 (Mini-AVR 21% and AVR 14%, $P = 0.19$) and >20 (Mini-AVR 3% and AVR 2%, $P = 1.00$) were similar in the two groups.

Intraoperative variables and perioperative support

Most valves implanted in both groups were tissue (mini-AVR 75% and AVR 81%, $P = 0.39$). The valve size was also comparable (mini-AVR 22 and AVR 22 mm, $P = 0.25$). Operative times were longer in the mini-AVR group (total operative time 198 vs 163 min, $P = 0.00000015$, cardiopulmonary bypass (CPB) time 88 vs 78 min, $P = 0.00040$, and cross-clamp time 66 vs 60 min, $P = 0.0078$). There has been a steady decrease in the time taken to perform the mini-AVR procedure over the study period, which we would suggest is the outcome of gaining experience with a new technique (example learning curve shown in Fig. 2).

Both cardiac and respiratory support provided during the patient's intensive care stay were similar in the mini and conventional groups (Table 2). Where inotropes were used, only three cases (two mini-AVR and one AVR) required more than one agent.

Postoperative complications and outcomes

Postoperative blood loss was significantly greater in the AVR group. Twelve-hour blood loss: mini-AVR 260 vs AVR 422 ml,

$P = 0.000013$. A larger percentage of conventional patients bled >500 ml at 12 h (Mini-AVR 8% vs AVR 33%, $P = 0.000024$). This difference persisted beyond 12 h; for total postoperative drainage Mini-AVR was 332 vs AVR 513, $P = 0.00021$.

Significantly more clotting products (fresh-frozen plasma and platelets) were transfused to patients in the conventional group (mini-AVR 24% versus AVR 37%, $P = 0.042$). However, despite a significantly higher blood loss from AVR, the number of patients receiving packed red blood cells was similar in the two groups (Fig. 3) at 12 h. Total postoperative blood transfusion was also similar (mini-AVR 43% vs AVR 56%, $P = 0.083$). The rate of reopening for bleeding was higher in the mini-AVR group, but not significantly so (Mini-AVR 5% vs AVR 2%, $P = 0.45$). Bleeding in this group came from the sternal wire holes in three cases and the aortotomy suture line in two cases.

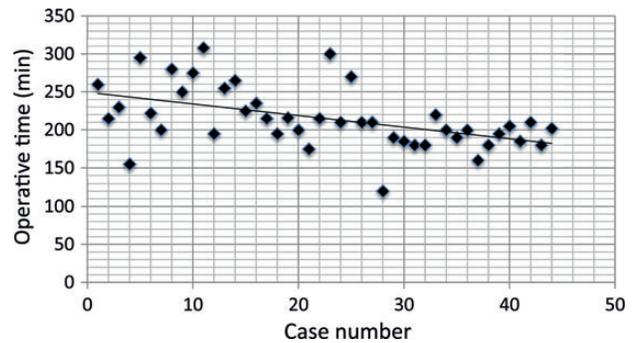


Figure 2: Decreasing operative times with experience (EA as surgeon).

ORIGINAL ARTICLE

Table 2: Perioperative support

	Mini-AVR	AVR	P-value
Inotrope use	9 (9%)	7 (8%)	0.80
Mean time to extubation in hours	25	24	0.96
Mean time to extubation excluding >48 h	9	8	0.66
>48 h intubation	8 (8%)	5 (5%)	0.57

AVR; aortic valve replacement.

Table 1: Demographic and preoperative risk factors

	Mini-AVR	AVR	P-Value
Mean age (range)	70 (19–86)	70 (21–87)	0.96
Male sex	58 (59%)	51 (55%)	0.56
Mean BMI	30	29	0.11
Obese: BMI >30	45 (46%)	36 (39%)	0.38
Asthma/COPD	26 (27%)	16 (17%)	0.16
Mean creatinine	93	90	0.56
Creatinine >120	13 (13%)	8 (9%)	0.36
Diabetes	17 (17%)	17 (18%)	1.00
Extracardiac arteriopathy	5 (5%)	1 (1%)	0.21
Stroke	8 (8%)	3 (3%)	0.22
NYHA Category III or IV	74 (76%)	70 (75%)	1.00
LV function <30%	8 (8%)	3 (3%)	0.22
Stenotic pathology	95 (97%)	92 (99%)	0.34
Mean logistic EuroSCORE	7	7	0.47
Logistic EuroSCORE >10	21 (21%)	13 (14%)	0.19
Logistic EuroSCORE >20	3 (3%)	2 (2%)	1.00

AVR: aortic valve replacement; BMI: body mass index; COPD: chronic obstructive pulmonary disease; NYHA: New York Heart Association Functional Classification for Patients with Heart Disease; LV function: left ventricular function.

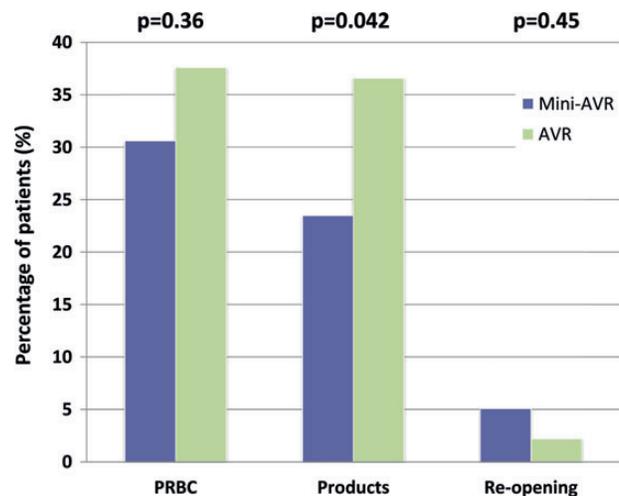


Figure 3: Treatment of postoperative bleeding in the first 12 h. PRBCs: packed red blood cells/products = fresh-frozen plasma and platelets/reopening = re-exploration for bleeding. AVR: aortic valve replacement.

Table 3: Postoperative complications

	Mini-AVR (%)	AVR (%)	P-value
Haemofiltration for acute kidney injury	6 (6%)	5 (5%)	1.0
Stroke	0 (0%)	1 (1%)	0.48
Atrial fibrillation	45 (46%)	31 (34%)	0.10
Requirement for permanent pacemaker	7 (7%)	3 (3%)	0.33
Deep sternal wound infection	1 (1%)	1 (1%)	1.0

AVR; aortic valve replacement.

Other postoperative complications were similar (Table 3). Most complications were rare. Postoperative atrial fibrillation was high but similar in both groups (mini-AVR 46% vs AVR 34%, $P = 0.10$). Postoperative echocardiography results (performed between Day 4 and 6 weeks) were similar in the two groups. There was a moderate to severe paravalvular leak in two mini-AVR and one AVR patient ($P = 1.00$). All three cases had a second aortic valve replacement performed via a full median sternotomy.

One superficial groin wound infection occurred in a mini-AVR patient. This complication was unique to the mini-AVR cohort due to the use of femoral venous cannulation. No other complications specific to the new procedure were identified.

Postoperative length of stay was similar in the two groups (mini-AVR 10 vs AVR 9 days, $P = 0.36$). Discharge on or before Day 4 was higher in the mini-AVR group, but not statistically so (mini-AVR 15% vs AVR 8%, $P = 0.17$). Most patients were discharged home but a small proportion required hospital transfer for acute care or rehabilitation (mini-AVR 10% vs AVR 7%, $P = 0.44$). In-hospital mortality was low in both groups (mini-AVR 1% vs AVR 3%, $P = 0.36$).

Conversions

Eight (8%) of mini-AVR patients were converted to a full sternotomy during the procedure. One of these was due to transection of the right internal mammary artery during ministernotomy. There were two perforations of the right ventricle from venous guide wires. Three patients were converted at the end of the procedure for aortotomy bleeding and two for cardiac instability and inability to wean from cardiopulmonary bypass. Preoperative risk for converted patients (EuroSCORE mean 6.88) was slightly lower than for the mini-AVR group as a whole (7.15). Conversions did lead to longer operative times (253 vs 198 min) and bypass times (110 vs 88 min), compared with the mean for mini-AVRs. However, cross-clamp time was similar (65 vs 66 min). Blood loss at 12 h was 419 in the converted group vs 260 ml for the mini-AVR group as a whole. As a result, the conversions accounted for over a quarter of those in the mini-AVR group that required blood or product transfusions, despite representing only 8% of the total mini-AVR cohort. However, rates of other complications were similar, as was length of stay. One patient required transfer to another hospital for continued care, but there were no deaths in this group.

DISCUSSION

The manubrium-limited approach has been described previously for standard AVR [4], and, more recently, for the implantation of

stentless valves [5]. However, most literature focuses on longer third to fourth intercostal space incisions. To our knowledge, this is the largest series of patients receiving a manubrium-limited incision and the first paper to compare the technique to conventional sternotomy.

A review of the existing literature highlights the heterogeneous nature of techniques used for minimal-access AVR. A few randomized, controlled trials exist, but patient numbers are small and often incorporate more than one minimally invasive technique [6, 7]. Several systematic reviews have been completed with large numbers of patients, but again include more than one approach [8]. In retrospective studies, advantages of minimally invasive techniques have been demonstrated, but, in an overview by Brown *et al.*, the small number of randomized, controlled trials did not elicit any significant differences [9].

In centres performing and reporting on their experience with minimal-access AVR, the proportion of operations carried out by this approach varies greatly. Approximate figures for the J-incision range from 14 to 46% [10, 11]. Our experience is at the higher end, with just over half (51%) of patients receiving mini-AVR in the first 18 months. In fact, from commencement of the programme, the two surgeons who learnt this technique performed >90% of their cases by ministernotomy. This illustrates the ease with which mini-AVR was integrated into our everyday practice and its acceptance by both patients and surgeons.

The rate of conversion to a full sternotomy ranges in the literature from 1.8 to 4% [9]. Our conversion rate was high at 8%. We have included our entire mini-AVR experience, from the first operation. Many studies do not state whether their initial cases are included, making comparisons difficult. Most of the existing papers use fourth intercostal incisions and so it is possible that this higher rate might be specific to the manubrium-only approach. Two of our reasons for conversion (right internal mammary transection and perforation of the ventricle by the venous guide wire) are likely to be specific and were initial problems encountered with using unfamiliar techniques that have now been overcome. Another case series using the manubrium incision had no conversions in 85 patients [4]. Also, other incisions have their own complications not witnessed in our study. For instance, with the J-incision, inadequate exposure, pre-CPB accounted for >50% of conversions in one study [12]. Bleeding and inability to wean from CPB were common problems shared between our technique and others [10]. Tabata *et al.* looked at both upper and lower sternotomy incisions. They noted that conversions in upper sternotomies tended to be more urgent, usually after the cross-clamp was removed and were associated with greater morbidity and mortality [13]. Most of our conversions were in the later stages of the operation. A systematic review also highlighted an association between conversion and poorer outcome [9]. In our study, patients who were converted had longer operative times and greater blood loss and transfusion. However, this did not result in longer stays or higher death rates. We have modified our technique over time to address the conversion rate, for instance improving our aortotomy closure to reduce the need for late conversions.

Our operative, CPB and cross-clamp times were longer in the mini-AVR group. A few studies [10, 12] have actually demonstrated shorter times with minimal access, but most studies agree with our findings. Overall, when compared with other studies, our timings for mini-AVR were within the reported range [8]. Of note, the actual differences in time between the mini-AVR and AVR groups were small (CPB 10 min and cross-clamp 6 min). This was borne out in a systematic review of other studies (CPB 11.5 and

cross-clamp 7.9) [9]. Valve insertion itself is technically no more challenging than in a conventional procedure, once the technique is learnt. However, we envisage our cross-clamp times will remain longer because of the need to insert drains and pacing wires while the clamp is on. We do not believe that this slight increase in cross-clamp time has led to adverse patient outcomes. Interestingly, times appear to be much shorter for midline ministernotomy techniques for CPB and cross-clamp (88 and 66 min in our study) than for minithoracotomy (123 and 89 min) in other centres [14].

Our study has shown a clear reduction in bleeding using the mini-AVR technique (total and 12 h). This may be due to the reduced size of the operative field and, therefore, less potential sites for bleeding, such as the sternum and pericardium. In most studies, blood loss is less in the minimally invasive group, although not exclusively so [6]. Values vary, but ours fall within the quoted range, far lower than in some studies—total drainage (mini versus AVR) 331 vs 513 ml in our study compared with 952 vs 1172 ml [11]. At 12 h, our mini-AVR patients had 162 ml less compared with the AVR group in their drains. This compared well with 24-h figures quoted in systematic reviews—64 ml less [8] and 79 ml less [9].

We also demonstrated a significantly reduced rate of product (fresh-frozen plasma and platelets) transfusion. We could find no existing literature against which to compare this. Despite lower rates of bleeding, a reduction in the use of blood transfusion was not seen. Part of this may be accounted for by the higher blood loss and transfusion rates in 'converted' patients who were included in the mini-AVR cohort on an 'intention-to-treat' basis. Many other studies have also failed to show a difference in blood transfusion rates [6, 11, 15]. However, this is not universal, with at least one randomized, controlled trial demonstrating lower rates of blood transfusion in the minimally invasive group: 37.5 vs 62.5% in the conventional group [7]. It is difficult to compare the number of patients transfused across studies because of variation in the time period analysed. Stamou *et al.* [15] focus primarily on blood transfusion giving postoperative rates of 45%, which was similar to our own 43% for mini-AVR. Notably, blood transfusion rates for minithoracotomy appear to be lower than ours, for example 18.8% in Glauber *et al.* [16]. Despite increased blood loss, we found no statistical difference in the rate of re-exploration for bleeding. Other studies that commented on this backed up our findings [7, 11].

Overall, we demonstrated that a learning curve existed for the operation (indicated by a reduction in operative times during the study period). One advantage of this article is that it covers our mini-AVR program from Day 1, giving a full insight into the issues encountered when introducing the technique (such as the need to convert to an open procedure). Reassuringly, however, morbidity and mortality were similar between the mini- and AVR groups, and we observed no difference in the rate of postoperative complications over the 18-month period. Therefore, we feel that, although a learning curve does exist, it had minimal impact on patient outcomes. This is in line with a previous study looking at aortic valve replacement via minithoracotomy, which demonstrated no increase in operative risk during the surgeon's initial experience with the technique [17].

There are several limitations to this study. It is a retrospective review looking at data from a single centre. Certain parameters, such as lung function and pain scores, were not available for analysis. However, it does include other variables not routinely described elsewhere (such as inotropic support and use of fresh-

frozen plasma and platelets). A randomized trial limited to one technique with sufficient power to detect differences in outcome is overdue. In the meantime, we feel this does provide new data on the manubrium-limited approach and represents the real-life implementation of a new procedure into practice.

With experience of just under 100 cases, we believe that the manubrium-limited sternotomy is a legitimate technique with several favourable characteristics. It produces the smallest possible incision for a midline approach. Unlike other midline incisions, such as the reversed C or L, it maintains the integrity of the entire body of the sternum. The V-shape provides a wedge effect, preventing lateral movement postoperatively. In contrast to the transverse sternotomy, it spares the internal mammary arteries [18] and does not require a special retractor. When required, extension to a full sternotomy is easily performed. We found the operative field adequate in all patients without the need for preselection, unlike in the anterior minithoracotomy approach, where a preop CT is required to confirm suitable anatomy [16]. For this reason, we believe that it is a reproducible technique, implementable by all surgeons.

In conclusion, the manubrium-limited approach had comparable outcomes to conventional sternotomy. Cosmetically, it provided a much smaller scar. In addition, there was less blood loss and a lower rate of products transfused. Therefore, we have advocated its continued use at our centre.

Conflict of interest: none declared.

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eComment. Further tips on partial sternotomy

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After cordially congratulating our colleagues from the James Cook Hospital on expanding limited sternotomy by limiting its length whilst improving results, I would like to add a couple of technical points concerning the now well-established upper hemisternotomy for aortic valve replacement: 1) On the preference card, paediatric defibrillator pads substitute for the adult-sized which surely do not fit in the manubriotomy. 2) The oscillating saw (known as a 'redo saw' in Britain) may substitute for the reciprocating one. I prefer it for an ergonomic advantage as well as avoidance of injuries such as the one described in the manuscript. I was recently offered an electric oscillating saw with a blade around one and a half inches that may take longer to saw, yet is accurate and useful in elderly osteoporotic manubria.

Conflict of interest: I perform and publish limited access surgery.

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