Evaluation of Different Minimally Invasive Techniques in Pediatric Cardiac Surgery*

Is a Full Sternotomy Always a Necessity?

Christian Hagl, MD; Ulrich Stock, MD; Axel Haverich, MD; and Gustav Steinhoff, MD

Study objectives: A variety of minimally invasive techniques have been recently introduced in adult cardiac surgery. Experiences with children and newborns are, however, limited. In this report, we present our first experiences with different methods of ministernotomies for closure of atrial septum defect (ASD) and ventricular septum defect (VSD) in pediatric cardiac patients. Also, the current literature for different surgical approaches is reviewed.

Patients and methods: Twenty-five pediatric patients (range, 4 months to 12 years old) underwent elective ASD or VSD closure. Surgical access was either without division of the sternum (group A, n = 5), with partial inferior sternotomy (group B, n = 5), total sternotomy with limited skin incision (group C, n = 5), or total sternotomy with full skin incision (group D, n = 10).

Results: There were no severe intraoperative complications regarding exposure, cannulation, or bleeding. Conversion to full sternotomy was not necessary in any patient. Bypass time and cross-clamp time in groups A, B, and C were comparable to the standard operation (group D). However, preparation time was significantly increased in one minimally invasive group (group A vs group D, p < 0.05). Despite general feasibility, the transxiphoidal access without sternotomy compromises exposure of the ascending aorta, resulting in impaired administration of cross-clamping, cardioplegia, and especially de-airing.

Conclusions: Transatrial pediatric cardiac operations can be performed without or with limited sternotomy. The partial sternotomy allows uncompromised exposure of the great vessels and should be favored over the transxiphoidal approach. The operative access and perioperative risk is comparable to a classical standard surgical approach. Advantages include improved cosmetic results in combination with a high degree of safety. (CHEST 2001; 119:622–627)

Key words: atrial septum defect closure; literature review; minimally invasive surgery; ministernotomy; pediatric cardiac surgery

Abbreviations: ASD = atrial septum defect; CPB = cardiopulmonary bypass; IVC = inferior vena cava; PTFE = polytetrafluoroethylene; VSD = ventricular septum defect

A variety of new minimally invasive techniques have been introduced in adult cardiac surgery. Advantages include a reduction of perioperative complications and an improved postoperative recovery. The shortened postoperative in-hospital stay and resultant lower cost of patient care, as well as a reduction of pain with an improved cosmetic result, have led to a widespread acceptance of these techniques in adults.

Experiences with cardiac surgery for infants and newborns are, however, limited. The reported approaches include a right anterior thoracotomy, a transverse inframammary skin incision with either a vertical sternotomy or bilateral transverse anterior thoracotomy, and video-assisted techniques.
Despite the challenge to minimize the surgical access, the introduction of new surgical techniques has to be considered carefully. The purpose of this study was to evaluate different minimally invasive approaches in pediatric cardiac patients. In contrast to a standard complete median sternotomy, we performed different types of ministernotomies for elective closure of atrial septum defect (ASD) and ventricular septum defect (VSD) in a small series of pediatric cardiac patients. Also, the current literature for different surgical techniques is reviewed.

**Materials and Methods**

**Patients**

Between September 1997 and August 1998, 25 consecutive pediatric patients (age range, 4 months to 12 years old; 16 female and 9 male patients) underwent elective ASD closure (n = 23) or VSD closure (n = 2; Table 1). In accordance with the surgeon’s preference, and after discussion in our cardiologic/surgical conference, surgical access was made without sternotomy (group A, n = 5), partial inferior sternotomy (group B, n = 5), total sternotomy with lower limited skin incision (group C, n = 5), or complete sternotomy with full skin incision (group D, n = 10). In one case of a 9-month-old infant with a previous tracheostomy and long-term ventilation due to pulmonary dysplasia, the inferior limited sternotomy (group B) approach was chosen to separate the stoma from the operative field.

All patients were operated on by the same surgeon. There was no medical reason why patients were assigned to one special surgical treatment group. Despite that fact, we tried to add young infants as well as older children in all groups, to allow more meaningful comparison.

**Surgical Technique**

All patients were placed in supine position, and a roll was used to elevate the inferior portion of the chest to improve the exposure. For safety reasons, external defibrillator pads were placed on the patient’s back and anterior left chest. A transesophageal echocardiography probe was inserted routinely to assess the surgical result as well as to detect possible intracardiac air. Either a full or partial sternal midline incision was performed, depending on the type of surgical access (Fig 1). In group A, a 3-cm skin incision was made and the processus xiphoideus was divided. A fixed arm retractor (Army-Navy retractor) was placed in the caudal portion of the xiphoid to elevate the sternum and improve the cranioanterior exposure. In some patients, cephalad retraction was performed with a Langenbeck’s hook placed and adjusted by an additional assistant. In group B and group C, a 4-cm to 6-cm inferior skin incision was performed, and the sternum was either divided up to the insertion of the third rib (group B) or completely split (group C). Patients in group D received a standard approach with full skin incision and full sternotomy. In all patients but those in group A, a standard pediatric chest retractor was used to spread the sternum. The thymus was partially resected, and the pericardium was opened across the right atrium and the ascending aorta. Stay sutures were placed at the free edge of the pericardium to improve exposure. The pleural space was not opened. The right auricle was carefully retracted with a single suture. Purse string sutures were placed and aortic cannulation was performed in the distal part of the ascending aorta with a plastic, guided flexible arterial cannula (Medtronic-Biomedicus; Duesseldorf, Germany). The superior vena cava was drained with a straight venous cannula (Medtronic-Biomedicus), and the inferior vena cava (IVC) was intubated with an angled cannula (Sorin; Stöckert, Germany). After establishment of cardiopulmonary bypass (CPB), the superior vena cava and the IVC were surrounded and snared to perform total CPB. After aortic cross-clamping with a right-angle cross-clamp, cardioplegic was administered through the aortic root. For CPB, moderate to mild hypothermia was used (28°C to 32°C). After induction of cardiac arrest, a standard incision of the right atrium was made beginning in the right atrial appendage, extending anterior to the sinoatrial area toward the IVC. A cardiotomy suction catheter was placed in the coronary sinus. If a direct closure of ASD was not feasible, a pericardial patch was used. Inlet VSD closure was performed by a transtricuspid approach using a polytetrafluorethylene (PTFE) patch. In all cases, special precautions were taken to maintain a blood level in the left atrium. After completion of reconstruction, removal of air was accomplished through the aortic root before the aortic cross-clamp was removed. Temporary endocardial pacing wires were

<table>
<thead>
<tr>
<th>Groups†</th>
<th>Age Range</th>
<th>Diagnoses</th>
<th>Operations</th>
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<tbody>
<tr>
<td>A (n= 5)</td>
<td>4 mo–10 yr</td>
<td>ASD II</td>
<td>Direct closure (n = 3), pericardial patch (n = 2)</td>
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<tr>
<td>B (n= 5)</td>
<td>9 mo–6 yr</td>
<td>ASD II (n = 4) Pulmonary dysplasia (long-term ventilation) with ASD II (n = 1)</td>
<td>Direct closure (n = 2), pericardial patch (n = 2) Pericardial patch</td>
</tr>
<tr>
<td>C (n = 5)</td>
<td>9 mo-5 yr</td>
<td>ASD II (n = 4)</td>
<td>Direct closure (n = 1), pericardial patch (n = 3) PTFE patch plastic</td>
</tr>
<tr>
<td>D (n=10)</td>
<td>10 mo–12 yr</td>
<td>VSD (n = 1)</td>
<td>Direct closure (n = 5), pericardial patch (n = 4) PTFE patch plastic</td>
</tr>
</tbody>
</table>

*ASD II = ostium secundum defect.
†Group A = subxiphoidal incision without sternotomy; group B = inferior incision with partial median sternotomy; group C = inferior incision with complete median sternotomy; group D = conventional surgical technique.
placed. When weaning from CPB, the pericardium was partially adapted and a single mediastinal drain was inserted. The sternotomy was closed with single sutures, subcutaneous tissue was adapted, and the skin was closed using an intracutaneous running suture.

Statistics

Because of the limited number of patients, we think that only descriptive statistics are appropriate. For comparison of operation times, a Student’s *t* test was used. A *p* value < 0.05 was considered statistically significant.

Results

In the ministernotomy groups, the length of the skin incision varied between 3 cm and 6 cm, according to the size of the patient and the length of the sternum. There were no severe intraoperative complications regarding exposure, cannulation, or bleeding, and there was no need to convert to the standard technique (full sternotomy) in groups A, B, and C. Although technically feasible, we believed that the transxiphoidal approach without sternotomy does not allow a comparable exposure of the ascending aorta. This limited access resulted in an impaired cross-clamping, administration of cardioplegia, and especially de-airing. The problem turned out especially in very small infants, where the view and working space is limited. Cranioanterior exposure either with a fixed arm retractor or performed individually by an additional assistant was unsatisfactory. Adequate manipulations on the aorta could only performed by caudal retraction of the vessel. In addition, the insertion of standard pediatric defibrillator paddles was extremely difficult.

Bypass time and cross-clamp time were comparable to the standard operation, whereas preparation time was increased in the minimally invasive groups (*p < 0.05* group A vs group D; Table 2).

All patients were extubated 6 to 12 h (mean ± SD, 7.1 ± 2.0 h) postoperatively. At the time of this study, fast-track extubation was not routinely performed in our institution. There were no bleeding events, and mean mediastinal drainage volume was comparable between groups. All drains were removed on the first postoperative day. Temporary atrial fibrillation was seen in one patient of group A and one patient of group C. All patients (except one child with a previous tracheotomy) were transferred from the ICU on the first postoperative day. Routinely performed postoperative echocardiograms showed no residual defect in any patient.

The further postoperative course revealed no complications regarding wound infection, sternal instability, or neurologic impairment. There were no differences in the recovery of the children. The average in-hospital stay was 10 ± 4 days (with no significant differences between groups).

The cosmetic results in the minimally invasive

![Figure 1. Schematic drawing of sternal access: transxiphoidal (group A), inferior sternotomy (group B), and complete sternotomy with partial (group C) or full skin incision (group D).](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21958/)

<table>
<thead>
<tr>
<th>Groups†</th>
<th>Total Operation Time, min</th>
<th>CPB Time, min</th>
<th>Aortic Cross-Clamp Time, min</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (n = 5)</td>
<td>121 ± 14‡</td>
<td>59 ± 12</td>
<td>38 ± 13</td>
</tr>
<tr>
<td>B (n = 5)</td>
<td>101 ± 24</td>
<td>56 ± 24</td>
<td>31 ± 20</td>
</tr>
<tr>
<td>C (n = 5)</td>
<td>91 ± 22</td>
<td>51 ± 22</td>
<td>33 ± 23</td>
</tr>
<tr>
<td>D (n = 10)</td>
<td>78 ± 16</td>
<td>48 ± 15</td>
<td>28 ± 19</td>
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*Values are given as mean ± SD.

†Transxiphoidal approach (group A), inferior sternotomy (group B), and complete sternotomy with partial (group C) or full skin incision (group D).

‡*p < 0.05* vs group D.
groups (groups A, B, and C) were considered good or excellent in > 90% and satisfactory for the other patients. Figure 2 shows the convincing cosmetic result after ASD closure through an inferior partial sternotomy (group B) for a 5-year-old girl. The advantage of a spatial distance to the tracheostoma is shown in Figure 3.

**DISCUSSION**

Early clinical studies using different minimally invasive approaches for pediatric cardiac surgery showed that transatrial closure of ASDs and VSDs for infants can be performed without sternotomy or by limited sternotomy.5–6,8–9,11

From our own experience, the limited inferior sternal approach can be safely performed for all infants requiring transatrial reconstructive procedures (ASD, VSD). The size of the incision and the length of the sternal division could be easily extended for better exposure if necessary. In this study, however, a 4-cm incision and division of the lower half of the sternum was sufficient in most cases. On the other hand, we believe that a transxiphoidal approach without sternotomy compromises exposure of the ascending aorta impairing cross-clamping, cardioplegia, and de-airing. The introduction of new technical devices, such as special retractors, and further experience may solve some of these problems. The unsatisfactory de-airing procedure, however, remains a serious and potentially dangerous problem. Although feasible, we believe that this method should not be recommended, especially for very small infants.

This finding is in contrast with reports from Barbero-Marcial and associates,10 who performed ASD closure through a xiphoidal process window approach with cannulation of the femoral artery and videoscopic assistance. An almost similar approach via a right thoracotomy using a video-assisted right anterolateral thoracotomy with the disadvantage of deep hypothermia and extensive long periods of extracorporeal circulation was performed by Chang and coworkers.12 In our opinion, these approaches are not necessarily less invasive, as they require special instruments and peripheral incisions with an...
additional risk of infections, lymphatic fistulas, peripheral nerve damage, and malperfusion. The issue of de-airing remains an unsolved problem. We strongly believe that the effort to minimize the surgical access should not compromise the safety of the operation. ASD and VSD closure are known to be low-risk and high-benefit operations. Therefore, the use of fancy but potentially dangerous techniques should not jeopardize the success of the procedure.

In our series, we did not observe any postoperative sternal instability or fractured ribs. This may be contributed to the soft formation and flexibility of the whole rib cage, especially in younger children.

In cases of patients with previous tracheostomy, modified surgical thoracotomy techniques were evaluated to minimize the risk of mediastinal infections.13,14 We believe that our approach with a limited skin incision and median ministernotomy is a reliable procedure to separate the operation field from the potentially infectious thoracostomy.

Alternatively to a median sternotomy, another effective approach for transatrial closure of ASDs, a right anterolateral thoracotomy for infants and adults, was revived by several investigators.15–17 The risk for right phrenic palsy by iatrogenic injury as well as the higher risk for postoperative atelectasis remains a clinical concern. Different reports show an incidence of phrenic nerve lesions from zero16 up to 16%.18 In addition, breast and pectoral muscle maldevelopment and scoliosis are known as long-term sequelae after anterolateral and posterolateral thoracotomies for children.19

The assessment of pain in pediatric cardiac surgery is difficult to analyze. It is known from experiences in adult cardiothoracic surgery that midline sternotomies and minirsternotomies are less painful than lateral thoracotomies.20,21 Furthermore, respiratory discomfort is more frequent after lateral thoracotomies.11 An attempt by a Boston group to show differences in postoperative pain levels in children after minimally invasive ASD closure vs full sternotomy failed to reach significance.7

Minimal-access surgery always raises the issue of minimizing the length of in-hospital stay and cost reduction. This question cannot be answered in this study. The length of in-hospital stay as well as costs are less apparent in the German socialized healthcare system, and patient discharge is influenced by much more factors than postoperative patient recovery alone. In this series, all patients were discharged after a standard postoperative treatment of 10 to 14 days, irrespective of the possibility for earlier discharge. Therefore, adequate conclusions about the influence of different surgical techniques on rehabilitation cannot be made by the length of in-hospital stay. On the other hand, it has been shown that early discharge after minimally invasive ASD closure is possible and safe.22 There is no doubt that the prolonged in-hospital stay in our study seems somehow contrary to the usually accepted “minimally invasive standards.”

The vertical skin incision centered on the lower portion of the sternum (group B) resulted in a cosmetically convincing scar. The high percentage of parents’ satisfaction concerning this cosmetic result confirmed our own impression.

**Conclusion**

Transatrial pediatric cardiac operations can be performed without or with limited sternotomy. Despite the small number of nonrandomized patients, we believe that a limited sternotomy does not imply compromises in exposure of the great vessels and should be favored over a transxiphoidal approach. The operative access and perioperative risk is comparable to the standard surgical technique. Advantages include improved cosmetic results in combination with a high degree of safety. We believe that our results favor a limited sternotomy over a lateral thoracotomy.

For children with tracheostoma, this approach can minimize the risk for wound and mediastinal infections by dividing the operation field from the potential infectious stoma area.

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