Thirty years’ experience of open-repair surgery for pectus excavatum: development of a metal-free procedure

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Abstract

OBJECTIVE: Throughout the history of surgery for pectus excavatum (PE), the Nuss procedure and open repair have been performed with many modifications, with most of these procedures using a metal bar. However, the use of a metal bar has several drawbacks. Thus, we aimed to develop a procedure that did not require a metal bar.

METHODS: Through our experience of 426 pediatric cases that underwent various procedures for open repair of PE at Nagoya City University, we arrived at the current procedure that we describe herein. We have evaluated this procedure by review of clinical results and deformity indices (Haller’s, steepness, excavation volume, and asymmetry index).

RESULTS: The latest and current procedure that supports the sternum with a bridge constructed by the 4th or 5th costal cartilages is associated with fewer complications, a lower re-operation rate, and striking improvement in the indices examined.

CONCLUSIONS: Our current open-repair procedure that does not require a metal bar is recommended for correction of deformities of PE in children.

Keywords: Open repair • Pectus excavatum • Deformity indices

INTRODUCTION

Since 1998, when Nuss et al. [1] advocated minimally invasive repair of pectus excavatum (PE), this procedure became the most favored surgery for PE. However, despite several technical improvements, it has some drawbacks, such as a high incidence of post-operative complications, post-operative pain, delay of return to activity, and the necessity of bar removal [2,3]. On the other hand, beginning in the mid-20th century, open repair of PE has been performed by those following Ravitch’s procedure [4]. This procedure has been modified to eliminate its shortcomings, such as weakness of sternal support, insufficient remodeling of the complex deformity, and possible retardation of growth of the thorax [5–7].

Since 1980, we have performed open repair of PE and have made several alterations leading to the procedure we are currently using. This report will show the process of the evolution of this procedure and results of evaluation of the current metal-free procedure.

MATERIALS AND METHODS

Patients

We have treated 488 patients (371 males, 117 females; aged 3–44 years, mean 9.46 ± 6.6) with PE, who have undergone open-repair surgeries in Nagoya City University. For this report, the patients were divided into two groups: the pediatric group (≤15 years of age, n = 426) and the adult group (>15 years of age, n = 62). The subjects are 426 pediatric patients, who had undergone metal-free open repair.

Evaluation of deformity

Deformity was evaluated by Haller’s index [5] and three original indices, which were calculated from the computed tomogram (CT) at the level of the greatest depression (Fig. 1).

\[
\text{steepness index} = \frac{D}{W} \times \frac{D}{W} \\
\text{excavation volume index} = \frac{IA \times IB + IA \times IB}{IA \times IB + IA \times IB} \\
\text{asymmetry index} = \frac{IA \times IB}{IA \times IB}
\]

CT was acquired preoperatively in all patients and about 3 years or over after surgery in follow-up visits.

Operative procedures

Over the years, we have modified the operative procedures because we were dissatisfied with the configurations (Table 1).
Series I consisted of 23 pediatric patients who were treated from July 1980 to April 1982. These patients underwent the original Ravitch procedure (Fig. 2(A)), which is characterized by (1) resection of total deformed cartilages, (2) detachment of the sternum from the xiphoid, perichondria, and intercostal muscles, and (3) transverse sternal osteotomy and tripod fixation, that is, fixation of the osteotomized sternum with a wedge of bone chip and overlap sutures of the obliquely transected bilateral 2nd or 3rd rib cartilages.

Series II was comprised of 19 patients who underwent surgery from February 1982 to April 1982. Characteristics of the surgical procedure during this period were (1) suturing of the sternum and rectus abdominal muscle and (2) plication of the perichondria of the removed rib cartilages and attachment to the sternum (Fig. 2(B)). These modifications of the Ravitch procedure were made to prevent occurrence of a depression below the xiphoid and paradoxical breathing.

Series III was comprised of 98 patients who underwent surgery from April 1982 to August 1996. In this series, two important modifications were adopted to strengthen the remodeled anterior chest wall: (1) shortening of the sternum by a 1–2 cm resection at the 5th intercostal level and (2) reduction of the length of the resected cartilages and suturing both stumps of the cartilages (Fig. 2(C)).

In series IV, there were 105 pediatric patients, 23 of which underwent adult-type procedures. In this procedure, an oblique osteotomy on the posterior table of the sternum was added to correct the twist of the sternum, and a bone chip was plombaged at this slit. Tripod fixation was continued (Fig. 2(D)). This procedure was planned mainly for adults. During the same period, a different procedure was developed for children. The tripod fixation was omitted because the sternum could be elevated easily only by resection of deformed cartilages in a child (Fig. 2(E)). The adult-type procedure was abandoned in 2002 because of difficulties in correction of a flat deformity and asymmetry without a metal strut in adults. After that time, adults were excluded from the objects for PE repair, and the pediatric-type procedure was transferred to the Vth pediatric-type procedure.

In series V, there were 181 pediatric patients. Sternal resection was performed at the 5th costal level, moving slightly to the cephalic side, to be supported by a bridge constructed with bilateral 4th or 5th rib cartilages (Fig. 2(F)). This procedure was developed to strengthen the sternal support by living material. This is the procedure currently performed.

Details of the procedure are as follows (Fig. 3 shows the scheme of the manipulations from (4) to (16b)):

1. Skin incision is median and longitudinal from just below the 3rd rib to the xiphoid level.
2. There is median separation of fascia of pectoralis major muscle and lateral sweeping of the bilateral pectoralis major muscles.
3. The osseous thorax wall is exposed by transverse transection of the rectus abdominal muscles along the 6th costal cartilages.
4. Subperichondral transection of abnormally deformed 3rd–7th costal cartilages at 1 cm lateral to the sternum bilaterally is performed to preserve the growth center of cartilage.
5. Deformed cartilages about 1 cm in length lateral to the cut points are removed. The 8th cartilages are shortened by several centimeters, if necessary, to prevent protrusion of the costal arch.

Table 1: Cases and periods of each procedure for correction of pectus excavatum

<table>
<thead>
<tr>
<th>Patients' age Series</th>
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<th>≥15</th>
<th>Total</th>
<th>Start</th>
<th>Finish</th>
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<tr>
<td>I</td>
<td>23</td>
<td>4</td>
<td>27</td>
<td>1980/7</td>
<td>1982/4</td>
</tr>
<tr>
<td>II</td>
<td>19</td>
<td>4</td>
<td>23</td>
<td>1982/2</td>
<td>1982/4</td>
</tr>
<tr>
<td>III</td>
<td>98</td>
<td>19</td>
<td>117</td>
<td>1982/4</td>
<td>1996/8</td>
</tr>
<tr>
<td>IV adult type</td>
<td>23</td>
<td>29</td>
<td>52</td>
<td>1982/4</td>
<td>2002/12</td>
</tr>
<tr>
<td>IV pediatric type</td>
<td>82</td>
<td>6</td>
<td>88</td>
<td>1983/1</td>
<td>1993/7</td>
</tr>
<tr>
<td>V pediatric type</td>
<td>181</td>
<td>0</td>
<td>181</td>
<td>1988/6</td>
<td>Present</td>
</tr>
<tr>
<td>Total</td>
<td>426</td>
<td>62</td>
<td>488</td>
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</tr>
</tbody>
</table>

Figure 1: Measurements for deformity indices. W: distance between the prominent points of the anterior chest wall on both sides; D: length of the perpendicular line between the center of the anterior table of the sternum and the line showing combination of both prominent points; rA: length between the right lateral thoracic wall and the vertical line from the center of sternum; rB: distance between the prominent point of right anterior thoracic wall and the touch line of right back; IA: length between the left lateral thoracic wall and the vertical line from the center of sternum; IB: distance between the prominent point of left anterior thoracic wall and the touch line of left back.

Figure 2: Transition of operative procedures [25].
The 7th costal cartilages on the vertebral side are resected.

In cases in which the bridge is constructed with the 5th costal cartilage, the 3rd, 4th, and 6th costal cartilages on the vertebral side are shortened and sutured to the 7th costal cartilages on the sternal side. Similarly, the 6th costal cartilages on the vertebral side are trimmed in a suitable manner and sutured to the same cartilages on the sternal side by five 1/0 absorbable threads. (16b) In cases in which the bridge is constructed with the 5th costal cartilages, the 3rd, 4th, and 6th costal cartilages on the vertebral side are trimmed in a suitable manner and sutured to the same cartilages on the sternal side by two 1/0 absorbable threads. Sutures are somewhat tense. (16a) In cases in which the bridge is constructed with the 5th costal cartilages, the 3rd, 4th, and 6th costal cartilages on the vertebral side are trimmed in a suitable manner and sutured to the same cartilages on the sternal side by two 1/0 absorbable threads. Sutures are somewhat tense. (16b) In cases in which the bridge is constructed with the 4th costal cartilages, the 5th costal cartilages on the vertebral side are shortened and sutured to the 6th costal cartilages on the sternal side. Similarly, the 6th costal cartilages on the vertebral side are shortened and sutured to the 7th costal cartilages on the sternal side (Fig. 3).

The 2nd, 3rd, and 4th intercostal muscles are sutured again to the same bundles.

(15) Anterior to the bridge, both ends of the sternum are sutured by five 1/0 absorbable threads.

(16a) In cases in which the bridge is constructed with the 5th costal cartilages, the 3rd, 4th, and 6th costal cartilages on the vertebral side are trimmed in a suitable manner and sutured to the same cartilages on the sternal side by two 1/0 absorbable threads. Sutures are somewhat tense. (16b) In cases in which the bridge is constructed with the 4th costal cartilages, the 5th costal cartilages on the vertebral side are shortened and sutured to the 6th costal cartilages on the sternal side. Similarly, the 6th costal cartilages on the vertebral side are shortened and sutured to the 7th costal cartilages on the sternal side (Fig. 3).

The 7th costal cartilages on the vertebral side are resected 2–3 cm and sutured to the sternum, but not tensely. Thus, the bridge of the 4th or 5th cartilages supports the caudal part of the sternum and the 6th and 7th costal cartilages, and protrusion of the costal arch is inhibited.

The separated bundles of the 2nd, 3rd, and 4th intercostal muscles are sutured to the reconstructed sternum.

Reapproximation of the pectoralis major muscles in midline is carried out, and the lower parts of these muscles are sutured to the rectal muscles along the 6th costal cartilages.

Finally, skin closure is accomplished.

Statistical analysis

Comparisons among the deformity indices were performed by t-tests, and the significance of differences between groups was judged by $p < 0.05$.

RESULTS

PE indices

PE indices calculated from 274 preoperative CT images from pediatric patients are as follows: Haller’s index $5.043 \pm 1.716$, steepness index $0.196 \pm 0.060$, excavation volume index $0.092 \pm 0.033$, and asymmetry index $1.093 \pm 0.18$. Comparisons of these results with those of adults (>15) are shown in Table 2. There were significant differences between the pediatric and adult groups in the Haller’s, steepness, and asymmetry indices. There are differences between patients number and CTs number because the indices were calculated, based on the available CT films at the time, when this article was written.

Postoperative complications

Complications were experienced in 26 cases (6.1%) (Table 3). The patient with hemothorax in the series V pediatric group was successfully treated by thoracentesis. All other complications were treated conservatively. Complications occurred more frequently in the early series and strikingly less in series V.

Re-operations due to recurrence of PE were performed in three patients in series I (13.0%), three (15.7%) in series II, 13 (13.3%) in series III, four (17.4%) in series IV adult type, four (4.9%) in series IV pediatric type, and one (0.5%) in series V. The only re-operation required in series V was a 5-year-old boy who was small for age. Although our follow-up revealed no sign of

<table>
<thead>
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<th>Index</th>
<th>Patients’ age</th>
<th>$&lt;$15 ($n = 274$)</th>
<th>$\geq$15 ($n = 22$)</th>
<th>$p$-Value</th>
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<td>Haller’s</td>
<td>$5.043 \pm 1.716$</td>
<td>$5.995 \pm 3.875$</td>
<td>0.01233</td>
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</tr>
<tr>
<td>Steepness</td>
<td>$0.196 \pm 0.060$</td>
<td>$0.170 \pm 0.069$</td>
<td>0.03023</td>
<td></td>
</tr>
<tr>
<td>Excavation volume</td>
<td>$0.092 \pm 0.033$</td>
<td>$0.102 \pm 0.050$</td>
<td>0.17409</td>
<td></td>
</tr>
<tr>
<td>Asymmetry</td>
<td>$1.093 \pm 0.18$</td>
<td>$1.178 \pm 0.286$</td>
<td>0.04822</td>
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</table>
recurrence, we were informed without a detailed explanation that he underwent re-operation at another hospital.

**Operation time and blood loss in series V**

Mean operation time in the 181 cases in series V was 180.6 ± 40.6 min, and mean blood loss was 133.6 ± 84.8 ml. No patient required blood transfusion.

**Hospital stay, drug management, and return to activity in series V patients**

Mean hospital stay was 11.47 ± 2.2 days in series V patients. At present, patients are discharged on the 8th postoperative day. Diclofenac sodium 25 mg per anus is administrated until postoperative day 2—4. Thereafter, analgesia is unnecessary. Patients can go to school 2 weeks after surgery, participate in sporting activity after 1 month, and participate in competitive sports after 3 months.

**Limitation in indication for the current procedure**

This procedure is not indicated for adolescents and adults because of the difficulty in constructing the costal bridge due to a rigid thorax.

**Evaluation of correction in series V**

The correction in the current procedure was evaluated by deformity indices in 133 patients whose preoperative and latest postoperative CTs were available. Mean interval between CTs was 111 ± 51.7 months. Mean Haller’s index was reduced significantly from 5.547 to 4.096 (Table 4). Steepness indices, corresponding to the degree of the V-shaped PE deformity, were also improved. Excavation volume indices, which correspond to the degree of a flat, broad depression, were improved as were asymmetry indices.

**DISCUSSION**

**Evaluation of deformity in PE**

Attempts at objective evaluation of the deformity in PE have been made over a long period. Although chest X-ray findings were used prior to 1970, the introduction of CT has become a source of more exact information.

Haller et al. established the transverse diameter/anterior—posterior diameter as an index of deformity in PE [5]. The anterior—posterior diameter indicates the distance between the sternum and spine at the level of the deepest depression, and the transverse diameter is the maximal transverse diameter of the thorax at the same level. The authors stated that this index was 4.42 ± 0.76 in PE patients and 2.56 ± 0.35 in normal subjects and useful in the judgment of operative indication.

Nakahara et al. used three indices to represent various characteristics of the deformity in PE patients as well as to evaluate postoperative improvement: degree of depression, degree of symmetry, and degree of flatness [8].

During our extensive experience in performing surgery for PE, we encountered subgroups of patients with differences in the characteristic of the deformity. Nuss et al. expressed these as having a cup shape, saucer shape, or Grand-Canyon shape [3]. We have established three indices to quantify these types of PE: (1) steepness index for the cup shape, (2) excavation volume index for the saucer shape, and (3) asymmetry index for the Grand-Canyon shape. The 2nd and 3rd indices are characterized as two-dimensional to quantify more exactly. Our indices can reflect the characteristics of each patient and reveal differences between groups; for example, there is a high incidence of asymmetry in adult patients.

Furthermore, as described later, we anticipate that these indices can be used as parameters to evaluate operative outcome.

**Evaluation of operative outcome**

Outcome of surgery for PE can be evaluated from several viewpoints, such as improvement in heart or lung function [9,10] and
improvement in subjective complaints [11]. However, correction of the thoracic configuration is the foremost expectation of most patients. The evaluation of such an outcome has been done subjectively by parents or patients in vague terms, for example, by selecting responses, such as excellent, good, fair, or poor [3,5,7]. However, evidence of the difficulty with this type of evaluation is that Kelly et al., in a report of satisfaction among both parents and patients, reported a rate of 85% of satisfaction in 95% of satisfied parents and 95% of satisfied patients [12].

The deformity indices, as mentioned above, have been used mainly for diagnosis of PE or judgment of operative indication. Nakahara et al. used them as a monitor for patients’ evaluations of operations [8]. Park et al. used their indices to evaluate the effects of operations and revealed improvements in indices [13].

We investigated the grades of correction by the current procedure using deformity indices and found striking improvements in all four. These results indicate that the procedure used in series V has excellent results for all types of PE deformities. Haller’s indices in preoperative and postoperative CTs were higher than Haller’s results [5]. We suppose that this might be due to the fact that the thorax is more flat in Japanese than in Caucasian children.

Selection of procedure

Nuss procedure. The Nuss procedure had merits, such as a minimal operative wound, lesser operative time, and lesser blood loss, but simultaneously has some demerits, such as frequent occurrence of complications, burden of bars remaining in place for a long time, and necessity of operation for removal of the bars [2]. Some of the complications might be life threatening, and dislodgement of the bar has been shown to necessitate re-operation or recurrence of the deformity [19]. To reduce these shortcomings, many modifications have been introduced, such as thoracoscopy and stabilizer for the bar [2, 14]. As a result, safety and efficacy of the Nuss procedure have improved, and its usage has increased.

Open repair. Those who favor use of the open-repair procedure have made various modifications with the aim to strengthen the reconstructed thorax [5–7]. Table 5 lists large series of procedures by open repair and the Nuss repair. A metal bar was used by most of those performing open PE repair. Saxena and Willital used three struts, two longitudinal and one transverse (Wittel–Hegeman procedure) [16]. Robicsek supported the sternum with a Marlex-mesh hammock [6].

Comparison between the operative results of the Nuss and the open-repair procedures. Few articles have compared the results of the Nuss and open-repair procedures because institutes performing both procedures are limited. Fonkalsrud et al. compared 68 Nuss and 139 open repairs in UCLA and South Carolina University and reported that the open-repair procedure required a longer operating time but showed decreases in hospital stay, complication rate, and use of pain medications [20]. Nasr et al. [21] reviewed nine articles on the performance of both procedures and found no difference with respect to overall complications and patient satisfaction. However, the rate of re-operation was higher with the Nuss procedure.

Pros and cons for a metal bar. We have paid closest attention to the use of a metal bar in PE repair. In the Nuss repair, it is left for 2 or more years and for over half a year in open repair. Although the bar can keep the thorax firm, it could cause delayed pain and inhibition of growth. Re-operation is needed for its removal, which might cause recurrence of depression after removal [22,23]. Furthermore, about 2% of persons have metal allergy [24].

All institutes listed in Table 5, whether the Nuss group or open-repair group, use a metal bar except Ravitch [15] and Robicsek [6]. We aimed to eliminate the use of the metal bar and reconstruct the bony thorax with the support of living tissues. Thus, we have established the current procedure.

The cartilages grow together with the growth of the bony thorax and continue to support the sternum. The reconstructed thoracic configurations have been maintained satisfactorily during 111 ± 51.7 months after surgery in 133 patients, excluding early postoperative (<3 years) patients and patients lost to follow-up. Longer operation time, more bleeding, and longer hospital stay have been pointed out as shortcomings of this procedure. However, elimination of the use of a metal bar could provide benefits that would overcome these drawbacks.

CONCLUSIONS

(1) An open-repair procedure without a metal bar for repair of PE was developed.

Table 5: Large series of open repair and the Nuss repair of pectus excavatum

<table>
<thead>
<tr>
<th>Author</th>
<th>Published</th>
<th>Cases</th>
<th>City (nation)</th>
<th>Remarks</th>
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<tr>
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<tr>
<td>Haller et al. [5]</td>
<td>1989</td>
<td>664</td>
<td>Baltimore (USA)</td>
<td>Strut</td>
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<tr>
<td>Saxena and Willital [16]</td>
<td>2007</td>
<td>1262</td>
<td>Graz (Austria)</td>
<td>Wittel-Hegeman procedure (3 struts)</td>
</tr>
<tr>
<td>Hu et al. [9]</td>
<td>2008</td>
<td>398</td>
<td>Sichuan (China)</td>
<td>Strut</td>
</tr>
<tr>
<td>Masaoka</td>
<td></td>
<td>488</td>
<td>Nagoya (Japan)</td>
<td>Support by bridge of costal cartilages</td>
</tr>
<tr>
<td>Nuss repair</td>
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<td></td>
</tr>
<tr>
<td>Dzielicki et al. [17]</td>
<td>2006</td>
<td>461</td>
<td>Gliwice (Poland)</td>
<td>Modified Nuss</td>
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<tr>
<td>Olbrecht et al. [14]</td>
<td>2008</td>
<td>244</td>
<td>Baltimore (USA)</td>
<td>Lorenz bar</td>
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<tr>
<td>Pilegaard and Licht [18]</td>
<td>2009</td>
<td>507</td>
<td>Aarhus (Denmark)</td>
<td>Absorbable stabilizer</td>
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<tr>
<td>Park et al. [13]</td>
<td>2010</td>
<td>1170</td>
<td>Ansan (Korea)</td>
<td>Modified Nuss</td>
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</table>
(2) The core of the procedure is shortening of the sternum and bridge formation by attachment of bilateral 4th or 5th costal cartilages.

(3) Complication rate was 2.8%, and re-operation rate was 0.5%.

(4) Evaluation of postoperative deformity indices showed significant long-term correction of the thoracic configuration.

(5) Metal-free open repair can be recommended for correction of PE in children.

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Conflict of interest: none declared.

REFERENCES


