Surgical repair of pectus excavatum not requiring exogenous implants in 113 patients

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Abstract

Objective: Pectus excavatum is relatively common congenital chest deformation that is often accompanied by physical and psychological impairment. The surgical methods for pectus excavatum repair are the subject of some controversy. We review our experience using a procedure in which the introduction of exogenous material is unnecessary.

Methods: From July 1993 to March 2008, 113 patients underwent surgical repair of pectus excavatum. Sterno-costal elevation was adopted for 102 patients, including all of the paediatric patients and most of the adults. Sternal turnover was employed for 11 adult patients with severe asymmetric deformities. In sterno-costal elevation, a section of the third or fourth to the seventh costal cartilages as well as the lower tip of the sternum below the sixth cartilage junction are resected, and all of the cartilage stumps are re-sutured to the sternum. The secured ribs generate 0.5—10 kg of tension, pulling the sternum bilaterally, such that the resultant force causes the sternum to rise anteriorly. These forces are sufficient to correct the deformities and to prevent flail chest. In sternal turnover, the sternum is cut at the third intercostal space. The lower part of the sternum is turned over and fixed to the upper sternum with an overlap of 1 cm. Sections of the third to the seventh rib cartilages are resected and affixed in the same fashion as in sterno-costal elevation.

Results: There were no operative deaths, and in all cases the deformities were corrected satisfactorily. Ninety-nine patients (88%) were graded as Excellent, and the remaining 14 (12%) were graded Good. None of the patients developed any life-threatening complications. No patient reported residual pain. No re-operations were required for any reasons. The patients resumed daily activities of all types, including contact sports, within 3 months after surgery.

Conclusions: We believe that morbidity is one of the most important factors to be considered in operative invasions. Our technique represents a less-invasive and lower-risk procedure for the repair of pectus excavatum in any age group.

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1. Introduction

Pectus excavatum is the most common congenital chest deformity. Patients with severe deformities suffer physical complaints, such as frequent respiratory infections, decreased endurance and impairment of weight gain from childhood, and even patients with mild deformities often complain of symptoms such as chest pain and palpitation after puberty [1—3]. Repair of pectus excavatum is undertaken to alleviate both physical complaints and psychological impairments [1—5]. The surgical methods for the repair of pectus excavatum have remained fairly controversial. The conventional Ravitch method requires potentially major invasive procedures [6]. Nuss described a novel method as a minimally invasive repair [7], but this was subsequently reported to have a relatively high incidence of complications [7—10]. In the present report, we have reviewed our experience using a novel procedure in which all of the cartilage stumps are secured, the tension exerted by the patient’s ribs work to correct the deformity and stabilise the thorax and the introduction of exogenous material is not a requirement. We re-evaluated the impact of invasive extent in the surgical repair of pectus excavatum on morbidity.

2. Materials and methods

From July 1993 to March 2008, 113 patients underwent repair of pectus excavatum by a single surgeon. There were 95 male and 18 female patients. Mean age was 13.9 ± 9.3 years of age, ranging from 3 to 44 years. The indication for surgery was evaluated from the appearance of the chest. If the depth and volume of the excavation were observed to exceed that of patient’s clenched fist, and informed consent for our surgical methods was obtained, the patient was recommended for surgical repair. No patient was excluded from surgical indication for reasons of the severity or...
asymmetry of the deformity. Three of the patients simultaneously underwent cardiac procedures.

3. Operative technique

We adopted two types of techniques [11]. Sterno-costal elevation (SCE) was used for 102 patients (12.8 ± 8.8 years old), a group that included all of the paediatric patients and most of the adult patients. The second technique used was sternal turnover (STO), which was employed for 11 adult patients (24.1 ± 10.6 years old) with severe asymmetric deformities.

In sterno-costal elevation, a median vertical incision was made in males, while an inframammary incision was used in female patients. The pectoralis and rectus muscles were exfoliated from the deformed sternum and cartilages. A part of the third or fourth to the seventh costal cartilages was resected. The pericartilages of mediastinal aspect were excluded from resection to prevent injury of the intrathoracic vessels and pleura. All of the cartilage stumps were re-attached to the sternum using #1 heavy thread or #3 braided polyester sutures. Adequate lengths of cartilage, from 5 to 60 mm, were resected, such that the re-sutured cartilages and ribs generated 0.5—10 kg of tension on the sternum. The resected length depended on body size and the degree of the deformity. Resected cartilages were generally longer, and the tensions generated by the ribs stronger, in the lower costae. In cases of asymmetric deformity, different numbers and lengths of cartilage were resected on each side. The secured ribs pulled the sternum to both sides, such that the resultant force caused the sternum to rise anteriorly. The tension exerted by the ribs was enough to correct the deformity and to prevent flail chest, but did not interfere with respiration. No incision into the upper sternum was performed, and exogenous materials to fix the lower sternum and ribs were unnecessary. The inner layer of the pectoral muscle and rectus muscle were sutured with sternum or cartilages, and the outer layer of pectoral muscles of both sides were sutured together to cover the field. The procedures have been improved over time. The exfoliation of the muscles has been limited to those that were attached to resected cartilages through a small incision (SCE II). The lowest point of the sternum is usually at the bottom of the excavation, and tilts back towards the vertebrae and exerts pressure on the heart and mediastinal components. For this reason, in the 77 most recent cases, the lower part of the sternum below the sixth cartilage junction was resected, and the sixth and seventh rib cartilages were secured to the lower cutting face of the sternum (SCE III) (Fig. 1). As a result of these modifications, the sternum is pulled caudally by the sixth and seventh rib cartilages, and correcting force on the deformed sternum is increased, pulling back the protruding costal arches, which are sometimes seen in patients with pectus excavatum. This modification could make SCE III adopt for most of adult patients, and correct protruding costal arches.

STO was employed for adult patients whose sternum was severely distorted. Costal cartilages were cut at the middle, and the sternum was cut at the height of the second intercostal space. The lower part of the sternum was then removed from the wound, turned over and fixed on the upper sternum using two metal wires, with an overlap of 1 cm (STO and overlap, STO II). An adequate length of each cartilage was resected, and all of the stumps of cartilages were attached to the plastron with sufficient tension. The sternal turnover procedure has also been improved over the years. In the most recent six cases, the sternum was cut at the third intercostal space, parts of the third rib cartilages were resected and re-sutured to the upper part of the sternum, and the lower sternum and ribs were fixed in the same fashion (STO III) (Fig. 2). This modification made it possible to reduce the size of the plastron and to raise the upper part of the sternum.

4. Results

There were no operative or in-hospital deaths. Mechanical ventilation was not needed after emergence from anaesthesia and, none of the patients received blood transfusions, with the exception of two patients who underwent concomitant aortic root replacements. The paediatric patients did not need epidural anaesthesia and postoperative sedation. The depression of the anterior chest wall was corrected, and asymmetric chest walls and protruding costal arches were improved. The result for 99 of patients (88%) was graded as Excellent (Figs. 3–8), and for the remaining 14 (12%) graded Good. No result was graded as Fair or Poor.
Fig. 2. Surgical technique of sternal turnover (STO) III. Parts of the deformed cartilages were resected, including the third cartilages (marked in black). The sternum was cut at the third intercostal space. The lower part of the sternum (marked in dark gray) was turned over and affixed to the upper sternum with an overlap of 1–1.5 cm, and the stumps of the all cartilages were secured to the sternum.

Fig. 3. Chest of 5 year-old boy with pectus excavatum before surgery. Severe pectus excavatum can be observed.

Fig. 4. One year after sterno-costal elevation (SCE). The length of the wound was 4.0 cm. Normal chest contour is seen.

Fig. 5. Chest of 25-year-old man with pectus excavatum before surgery.
wounds were inconspicuous, and the length of the vertical wound in 35 males below 7 years of age was $4.2 \pm 0.7$ cm, 6.8 ± 2.0 cm in 7—15-year-olds ($n = 22$), and 8.5 ± 2.4 cm in the patients over 15 years ($n = 38$) who underwent SCE.

Two patients developed pneumothorax, and one developed a superficial wound infection, but none developed any life-threatening complications. Patients could take analgesia at their request, but none of the paediatric patients received analgesia beyond the third postoperative day. No patient reported residual pain. No re-operations were required for any reason. Patients were able to return to their preoperative daily activities within a week of surgery without analgesia, and returned to school or work within 4 weeks.

Patients resumed all types of activities, including contact sports, within 3 months after surgery.

At 1 year after surgery, slight deterioration of postoperative appearance was seen in nine adolescent and adult patients (aged $20.8 \pm 8.7$ years), but their chest contour was nonetheless much better than that prior to surgery.

5. Discussion

The purposes of surgical repair for pectus excavatum are to relieve compression caused by the chest deformity, so as to prevent pulmonary and cardiac dysfunction, as well as to alleviate physical and psychological complaints and to allow normal growth of the thorax [1—5, 12]. Most conventional techniques for the repair of pectus excavatum have been based on methods first described by Ravitch, involving a long incision in the anterior chest wall, resection of cartilages, tearing of the sternal cortex and securing only a part of the cartilages [6]. Several modifications have been reported by Haller, Fonkalsrud, Robicsek and others, some of them require the introduction of implants to stabilise the sternum [1—3, 12, 13]. Such procedures can be employed in any age group, and in patients with severe deformity, but are complex, technically demanding and invasive.

A revolutionary procedure was reported by Nuss in 1998 [7]. Neither an anterior wound nor the cutting of cartilage or sternum is required, but a metal bar is placed behind the sternum through the pleural cavities. This procedure has gained popularity, but has been associated with relatively high morbidity and recurrence rates. Re-operation for complications, such as dislocation or infection of the bar, has been reported in 4—11% of cases [7—10]. Residual pain is one of the unpleasant complications of this procedure [8, 14] and may be sufficient to disturb daily activities. The pectus bar seems to be linked to many of the complications. The components of the thorax are much more fragile than metal and require natural flexibility to permit respiration and body movements. Moreover, in children of the age at which surgical correction is often performed, the thorax continues to grow for years. The bar is left inside the patient for 2—4 years, and they are unable to do contact sports for this
period. Because the majority of pectus excavatum corrections are performed in young patients who have maintained acceptable quality of life preoperatively, the experience of residual pain, unscheduled re-operation or long-lasting limitations on ordinary school and sports activities may have more negative impacts than the chest deformity itself. We believe that morbidity rate is a more important factor to consider in providing surgical invasion than which part of the body is cut or resected.

Wada and colleagues have described surgical procedures for funnel chest since 1959 [15], and the original SCE procedure was developed in 1981 [16]. They were aware that the ribs and cartilages of patients with pectus excavatum were longer, and the inclination of ribs was steeper than in unaffected patients. Our goals for correction of pectus excavatum are to normalise the structure and function of the thoracic cage, and to re-fashion a physiologically normal thorax. The difference between our methods and others is that in our methods the resilience exerted by shortened and re-sutured ribs is utilised to correct the deformed chest wall and to stabilise the thorax. Neither the triangular resection of the sternal cortex in the Ravitch method, nor the implantation of exogenous materials is required. In our procedures, the sternum is pulled laterally by shortened and re-sutured costal cartilages, and the resultant force raises the sternum ventrally. This pulls the ribs and corrects their steep inclination and the protrusion of the costal arches at the same time. Because we secure all of the cartilage stumps, the resilience of each rib helps to correct the chest-wall deformity without the need for exogenous implants. The same force prevents flail chest, while allowing patients to breathe independently immediately after surgery. Because we resect only a part of each cartilage and affix all of them, the procedure does not affect the growth of the thorax and does not cause restricted thorax, which is a potential complication after massive resection of cartilage [17]. Since parts of the longer cartilages were resected, recurrence was rare.

We have improved these techniques to make them less invasive, with less morbidity. As a result of resection of the lower tip of the sternum, the sternum was pulled caudally by the sixth and seventh rib cartilages, and correcting force was increased. Before we adopted the partial resection of lower sternum, 19% of the patients underwent STO, but after we adopted resection of the lower tip of the sternum (SCE III), only 6.3% of patients underwent STO procedures. In adult patients with severe asymmetrical deformity, the sternum is so twisted that it must be cut, and STO be performed. In STO III, the sternum is cut at one intercostal space lower than previously to reduce the size of the plastron. Since the plastron was sandwiched between the blood-rich mediastinal aspects of the pericartilages and intra-thoracic vessels, and the pectoral muscles, we did not observe necrosis of the plastron.

These two procedures can be used for any age group and grade of deformity. They also provide excellent postoperative contours, and are associated with low risk of surgical complications. We do recommend that in many cases the most appropriate age for surgical correction for this condition is 5—10 years. Most paediatric patients do not have severe physical and psychological complaints preoperatively, suggesting that there is no urgency before they are 5 years old, and 5-year-old patients are increasingly capable of understanding the meaning of the surgery. Adolescent and adult patients, on the other hand, tend to have physical complaints and to require longer incisions. Some of the patients in this age group experienced slight deterioration of the contour 1 year after surgery. So we feel it is optimal to correct the deformity before that age. A few paediatric patients with severe depression of the anterior chest complain of appetite loss and impairment of weight gain, which may be the result of the compression of the stomach by the deformed chest wall. This patient group may need to undergo corrective surgery before the age of 5. Loss of appetite is usually ameliorated after surgery.

6. Conclusions

An excellent postoperative chest contour was achieved, and none of the patients developed major complications. As pectus excavatum patients generally maintain an acceptable quality of life preoperatively, surgeons have a strong obligation to avoid the risk of complications and postoperative limitations on daily activities. We believe that our technique represents a less-invasive and lower-risk procedure for the repair of pectus excavatum.

References

Appendix A. Conference discussion

**Dr F. Robicsek** (Charlotte, North Carolina, USA): I have a question regarding this very interesting material presented. You used two methods. The first was the simple reattachment of the perichondrium, a technique which was used extensively in Mark Ravitch’s time in the early ’70s and yielded an unacceptably high recurrence rate. I’m surprised that you didn’t have any. How did you do it? You later modified this procedure by placing a Marlex hammock and that prevented all complications.

My second question concerns the sternal turnover. I have seen Dr Wada doing his original operation. He did not use just a simple turnover, but he took a big hammer and just beat the daylights out of the sternum to make it flat. My remark to the turnover technique is, that if you do a lot of sternal turnovers, one of these times you are going to have a sternal necrosis, one of the most horrible complication anybody can have.

**Dr Iida**: To answer both questions, it is tension exerted by rib cartilages. With both of our techniques we resect only a part of the rib cartilages. In children each rib creates about 0.5 kg of tension, and in the adult patient, almost 10 kg of tension was exerted from each rib. So the tension corrects the chest wall very well, and I think this tension prevents relapse or recurrence. Our recurrence rate is very rare.

**Dr J.R.M. De Campos** (Sao Paulo, Brazil): Dr Wada published many years ago that with the turnover, they not only have the necrosis but they have infection, and one of his assistants KEEP IN PLACE the mammary artery to prevent this complication. Are you still using this preventing maneuver?

**Dr Iida**: Actually, recently I removed the lower part of the sternum. I cut out at about the height of the sixth cartilage junction, and then we resutured the sixth and the seventh rib cartilages to the lower cutting face of the sternum, so the sternum is pulled under, downward, by resutured ribs. So we can adopt our sternocostal elevation even for the adult patient. Recently we adopted turnover for about, well, less than 3% of patients, for very severe deformity, like Marfan syndrome. Recently most of our patients get sternocostal elevation.

**Dr H. Pilegaard** (Aarhus, Denmark): Why are you doing a sternal turnover? You could probably do one or two osteotomies and then you could get a straight sternum. Why are you turning the sternum instead of just doing an osteotomy or two?

**Dr Iida**: After our operation, the patient gets a straight chest wall, not bent. I think it will be much better than before, and our patients go back to being very active in 3 months. Our patients didn’t need to have a foreign body removed. So I think it’s a very important thing for children.

**Dr J. Amato** (Chicago, Illinois, USA): My first comment: I, too, really am concerned about the Nuss procedure. Perhaps it’s my age and perhaps it’s because Dr Robicsek taught me his modified methods, but no one in discussing this procedure has brought out the fact that there have been several types of complications, such as hemorrhage from perforation of the atrium or hemorrhage because of getting into the pericardium. I’m just wondering how you avoid these things.

My second comment: No one has mentioned the incision in regard to females. When I have done females, I have done the submammary incision as taught to me by Dr Brom because I feel it’s much more cosmetic in young ladies. I just would like to hear some comments either from you or from the previous speaker.

**Dr Iida**: We use an inframammary horizontal incision for female patients. We can see directly. We don’t experience bleeding.