Pectus Excavatum Repair: Review of 80 Cases in 32 Years

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We examined the results for pectus excavatum (PE) repair using conventional methods   sternal elevation by modified Ravitch procedure (SEMR), sternal elevation elevation by metal struts (SEMS), sternal turnover (ST) and costoplasty (CP)   and minimally invasive repair of PE (MIRPE) in 80 patients (65 boys and 15 girls) operated between July 1972 and March 2005 at the First Department of Surgery, Nagasaki University Hospital. Of 80 patients, 23 (28.8%) had asymmetric PE, while 57 (71.2%) had symmetric PE. The medians of cosmetic appearance index, functional impairment index and CT index were 0.022, 0.160 and 5.0395, respectively. A significant ($p<0.0001$) difference was observed among the operative methods for operating time, blood loss and hospital stay; the median of operating time was 85, 252.5, 145, 170 and 170 min for MIRPE, ST, CP, SEMR and SEMS, respectively; the median of blood loss was 5, 299.5, 243, 105.5 and 547.5 mL for MIRPE, ST, CP, SEMR and SEMS, respectively; the median of hospital stay was 10, 18.5, 30.5, 9.0 and 23.5 days for MIRPE, ST, CP, SEMR and SEMS, respectively. Postoperative complications were noted in 23 patients (28.8%), and the most common complication was wound infections. Epidural analgesia was used for postoperative pain control in 12 (75.0%) of 16 patients receiving MIRPE and 4 (7.7%) of 52 patients receiving ST in 1991 or later. The present study suggests that SEMR and MIRPE will be most versatile methods for children among the 5 operation procedures because of minimum invasion and short hospital stay; MIRPE has advantages that it has no incision of anterior chest wall and that it does not require resection of rib cartilages.

Introduction

Pectus excavatum (PE) is a congenital chest deformity most frequently seen in children. It is characterized by depression of the anterior thoracic cage, occurring approximately in 1 per 300 to 400 births.[1-3] It is recognized at birth in most cases, is slowly progressive, and becomes more obvious during the pubertal growth spurt. Boys are affected approximately 4 or 5 times more often than girls.[2,4] Symptoms are uncommon during early childhood. However, a shy awareness may occur according to deformity of the chest wall. The sternal elevation and the sternal turnover procedures have been standard for the repair of PE until recently. In 1998, a minimally invasive repair of PE (MIRPE) was introduced by Dr. Nuss and his colleagues.[5,6] This new procedure remodels deformed chest wall using metal bar without cartilage resection, and is expected to have better cosmetic outcomes than conventional procedures. Between July 1972 and August 1999, we performed PE repair to 65 patients by Ravitch procedure, sternal turnover or costoplasty, while we performed MIRPE to16 PE patients since 2001. In the present study, we retrospectively investigated the results in PE patients operated by conventional methods or MIRPE at the First Department of Surgery, Nagasaki University Hospital.

Patients and Methods

Eighty-one PE patients (66 boys and 15 girls), aged 2 to 26 years, underwent repair of PE between July 1972 and March 2005. Sixty-five of them received the surgical repair by sternal elevation by modified Ravitch repair (SEMR), sternal elevation metal struts (SEMS), sternal turnover (ST) (free sternal turnover, the mammary artery or rectal muscle preserved) and costoplasty (CP) between July 1972 and August 1999, while 16 patients received thoracoscopy-assisted MIRPE since August 2001. As the metallic plate for MIRPE, stain-
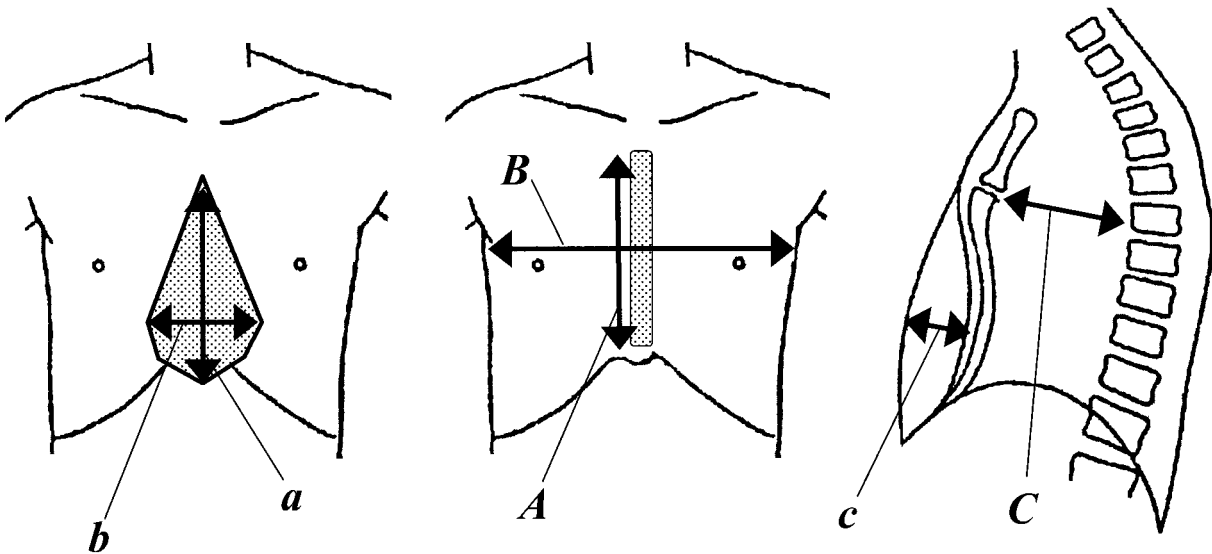
Figure 1. Calculation of funnel index (FI): a　longitudinal length of deformity, b　width of deformity, c　depth of deformity, A　length of sternum, B　width of chest, C　minimum length between angle of sternum and anterior part of vertebra. $F_1I=c/(a\times b)$ and $F_2I=(a\times b\times c)/(A\times B\times C)$.

less steel bar was used in the first 8 patients, and then changed to titanium alloy bar. The bar was fixed to the chest wall with right-side stabilization device for stainless steel bar, while with both-side device for titanium alloy bar.

Among these 81 PE patients, we excluded one patient from the analysis since no records except for the sex and the method were available.

We compared clinical findings, associated congenital anomalies and postoperative course among the above-mentioned 5 operative procedures. Morphologic chest wall deformity was classified into symmetric and asymmetric types. In the symmetric type, the respective centers of sternum and depression were collocated, while in the asymmetric types, the center of depression was not located in the center of sternum being shifted to one side. We assessed the severity of PE by funnel index (FI) and CT index. FI has two parameters called cosmetic appearance index (F_1I) and functional impairment index (F_2I). F_1I and F_2I are defined as $c/(a\times b)$ and $(a\times b\times c)/(A\times B\times C)$, respectively, where a denotes longitudinal length of deformity, b　width of deformity, c　depth of deformity, A　length of sternum, B　width of chest, and C　minimum length between angle of sternum and anterior part of vertebra (Figure 1). We classified the levels of cosmetic impairment into 3 categories on the basis of F_1I: mild　$F_1I<0.02$; moderate　$0.02\leq F_1I\leq 0.03$; and severe $0.03<F_1I$. Similarly, we classified the levels of functional impairment into 3 categories on the basis of F_2I: mild　$F_2I<0.2$; moderate $0.2\leq F_2I\leq 0.3$; and severe　$0.3<F_2I$. We defined CT index as a/b, where a denotes the internal transverse distance and b denotes vertebra-sternal distance determined on CT scans (Figure 2). The CT index exceeding 2.5 was considered significant and the index exceeding 3.2 was generally considered to indicate a severe deformity.
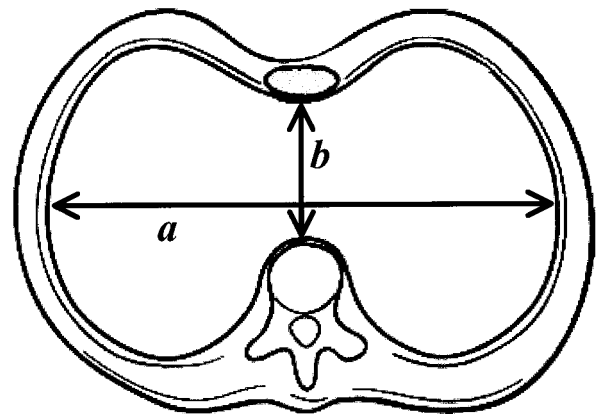
Figure 2. Calculation of CT index: a　internal transverse distance, b　vertebral-sternal distance at most depressed portion. CT index=a/b.

Results

Clinical data are summarized in Table 1. The age of clinical appearance of deformity was available for 77 patients among whom 32 (41.6%) were noted deformity at birth. The age of clinical presentation varied from 0 to 13 years with the median (2nd quartile or 50th percentile) of 1 year; the 1st (25th percentile) and 3rd (75th percentile) quartile were 0 year and 4 years, respectively. The age at consultation varied from 2 to 26 years with the median of 11 years; 1st and 3rd quartiles were 6.5 and 14.5 years, respectively. Scoliosis was the most frequent associated findings and was present in 7 patients. Eleven patients had frequent episodes of upper respiratory infection. Two patients received previous pectus repair of CP and SEMR.

Of 80 patients, 23 (28.8%) had asymmetric PE, while 57 (71.2%)

Table 1. Clinical data in 80 patients with pectus excavatum

Parameter	Number of subjects with data	Distribution
Sex (Male/Female)	80	65/15
Age at manifestation of deformity (year)	77	(0, 1, 4)[a]
Age at consultation (year)	80	(6.5, 11.0, 14.5)
Height (cm)	80	(119.7, 137.5, 166.0)
Weight (kg)	80	(20.6, 29.2, 48.2)
Scoliosis (Yes)	80	7 (8.8%)
Frequent episodes of upper respiratory infection (Yes)	80	11 (13.8%)
Previous pectus repair (Yes)	80	2 (2.5%)

[a]Each triplete denotes the 1st quartile (25th percentile), 2nd quartile (50th percentile or median) and
3rd quartile (75th percentile).

Table 2. Performance of operative methods for pectus excavatum

Parameter	Operative method[a]				
	CP n=4	SEMR n=4	SEMS n=4	ST n=52	MIRPE n=16
Operating time (min)	(105, 145, 195)[b] 90-220[c]	(130, 170, 225) 105-265	(145, 170, 220) 125-265	(207.5, 252.5, 295) 120-520	(66, 85, 122) 48-251
Blood loss (mL)	(62, 243, 678.5) 45-950	(55.5, 105.5, 249) 20-378	(377.5, 547.5, 657) 245-729	(177.5, 299.5, 556) 55-2480	(0.75, 5, 10) 0-20
Length of hospitalization after operation (day)	(23, 30.5, 48) 20-61	(6.5, 9, 20) 6-29	(21, 23.5, 25) 20-25	(15, 18.5, 25.5) 11-69	(7.5, 10, 56) 7-56

[a]CP=costoplasty; SEMR=sternal elevation by modified Ravitch; SEMS=sternal elevation by metal struts; ST=sternal turnover;
MIRPE=minimally invasive repair of PE; and n denotes the number of patients receiving respective methods.

[b]Each triplete denotes the 1st quartile (25th percentile), 2nd quartile (50th percentile or median) and 3rd quartile (75th percentile).
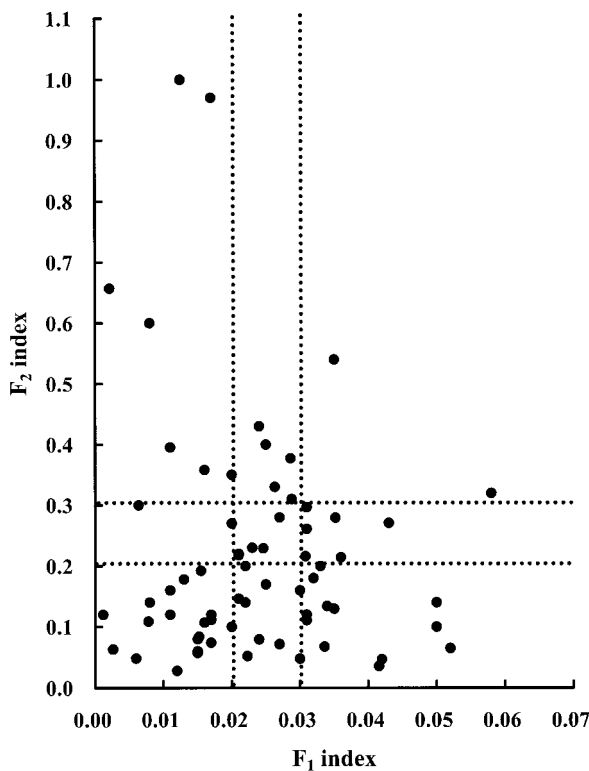
[c]Minimum-Maximum.

had symmetric PE. Both F_1 and F_2 indices were available in 71 patients; F_1 varied from 0.001 to 0.082 with the median of 0.022, 1st quartile of 0.015 and 3rd quartile of 0.031; and F_2 varied from 0.028 to 1.000 with the median of 0.160, 1st quartile of 0.100 and 3rd quartile of 0.280. Out of 71 patients, 18 (25.4%) had F_1 and F_2 indices under 0.02 and 0.2, respectively (Figure 3). CT index was available in 28 patients; it varied from 3.226 to 11.615 with the median of 5.0395, 1st quartile of 4.460 and 3rd quartile of 8.1445.

Operative data are summarized in Table 2. Out of 64 patients receiving conventional operations, 4 each underwent CP, SEMR, SEMS and 52 underwent ST. There were no deaths after either procedure, and no patient required postoperative admission in an intensive care unit. A significant difference among operative methods was observed in each of the distributions of operating time, blood loss and the length of hospitalization after operation ($p<0.0001$; Kruskal-Wallis test).

Postoperative complications were noted in 23 patients (28.8%) (Table 3). The most common complication was wound infection, which was noted in 14 patients. A boy receiving MIRPE developed erythema and drainage of pus from both thoracic wounds was

required 10 days after operation (on POD 10). He complained of retrosternal pain with fever. Culture of the pus yielded methicillin-sensitive *Staphylococcus aureus*. On both sides, the extremities of the metal plates were visible in the open wound. Treatment with intravenous antibiotics (Cephazolin sodium and gentamycin) was started. On POD 20, methicillin-resistant *Staphylococcus aureus* was isolated from the pus. Antibiotics were switched to Imipenem/cilastatin sodium and arbekacin sulfate, and treatment was continued for further 2 weeks. He was discharged on POD 56 with the plate in place. Another MIRPE patient who received two-plate correction was re-hospitalized due to plate dislocation within 1 month after operation, and required re-operation for removal of one plate and reposition of the other plate. Two patients receiving ST with free sternal flap developed bone necrosis. One CP patient developed a sternal re-depression two months after operation. He was not satisfied with the results of initial operation and received re-operation with ST one year after initial operation.

Epidural analgesia became available to children since 1991 in our hospital for controlling postoperative pain. Postoperative epidural analgesia was used in 12 (75.0%) of 16 patients receiving MIRPE

Discussion

Various surgical techniques for PE are currently available.[1,2,4,7,8] Despite many procedures that have been described, no method can provide optimal functional and cosmetic results. In this study, we described the transition of operative methods and compared the results of each repair performed in our department for 32 years. However, the review suffered from several limitations arising from the presence of such as multi-operators, a learning curve for operation, and technological advances.

We use F_1 and F_2 indices to objectively estimate PE severity and to identify patients who warrant surgical repair. We have been using since 1988 an additional parameter of CT index which demonstrates severity and asymmetry property of the chest wall deformity. CT scans also document more clearly the degrees of cardiac and lung compression, and other unexpected issues. All of our patients with mild impairment in both of cosmetic appearance and functional ability underwent a repair if CT index classified them to the category of the severe deformity because the patients or their parents insisted on having the repair for cosmetic reasons. The repair was not decided based on F_1 and F_2 indices alone; CT images and CT index could be helpful in making more objective judgment on proceeding to surgery. Today, the indications for repair are mainly based on cosmetic and psychological factors.

There are various opinions concerning the optimal age for repair.[5,6,9] The repair with deformed costal cartilage resection can be performed more easily at the ages of 2 to 5 years than at the ages of later years. However, some authors have cautioned that resection of large segments of the deformed costal cartilages in young children may interfere with the rib growth plates.[1,4] MIRPE excludes the risk of chest wall growth disturbance because of no cartilage resection or sternal osteotomy, and can be performed safely in young children. The ideal age for MIRPE is 6-12 years, because the thorax with advancing age loses its malleability and needs more implant bars for increasing load to remodel the deformity.

In comparison of postoperative results, patients receiving MIRPE showed shorter operating time, less blood loss and shorter hospital stay than those receiving conventional operations. The technical simplicity and minimal operative invasion of MIRPE were proved

Figure 3. Scatter plots of cosmetic appearance index (F_1 index) and functional impairment index (F_2 index) in 71 operated patients. The levels of cosmetic impairment were: mild F_1I<0.02; moderate $0.02 \leq F_1$I≤ 0.03; and severe $0.03 < F_1$I. The levels of functional impairment were: mild F_2I<0.2; moderate $0.2 \leq F_2$I≤ 0.3; and severe $0.3 < F_2$I.

and 4 (7.7%) of 52 patients receiving ST in 1991 or later; the duration of epidural analgesia in patients receiving MIRPE varied from 1 to 10 days with the median of 4 days, the 1st quartile of 2.5 days and the 3rd quartile of 7 days, while in patients receiving ST, it varied from 2 to 8 days with the median of 5.5 days, the 1st quartile of 3 days and the 3rd quartile of 7.5 days.

Table 3. Postoperative complications by operative methods

Complications	Operative method[a]				
	CP n=4	SEMR n=4	SEMS n=4	ST n=52	MIRPE n=16
Wound infection	1	0	0	10	1
Skin or bone necrosis	0	0	0	2	0
Atelectasis	0	0	0	5	0
Others	1	0	0	3	0

[a]CP=costoplasty; SEMR=sternal elevation by modified Ravitch; SEMS=sternal elevation by metal struts; ST=sternal turnover; MIRPE=minimally invasive repair of PE; and n denotes the number of patients receiving respective methods.

by blood loss not exceeding 20 mL in all patients receiving MIRPE. Early postoperative complications of the open procedures have been well described in literatures. In our series, wound infection was the most common complication, and thought to be caused by high operative invasions such as the high extent of necessary dissection, long operating time and much blood loss. One patient receiving MIRPE developed a postoperative infection. For operation using implanted prosthetic devices, infection is one of dreaded complications and frequently necessitates removal of the devices.[10] The incidence of wound infections after MIRPE is reported to be 2.3%.[9,11,12] However, these infections can be controlled by early diagnosis and antibiotics treatments, and eventual bar removal is reported to occur in only 0.7% of patients receiving MIRPE.[11,12] Sternal bone necrosis was seen in two patients receiving early ST. Early ST with free sternal flap includes possible bone resorption or necrosis, and later ST preserves the internal mammary vessels or rectal muscles. The most severe complications in MIRPE procedure have been reported as cardiac and pericardial injuries caused by unaware passage of a bar into the mediastinum.[11,13,14] We initially used both-side thoracoscopy to prevent the injury, and observed no severe complications during operation. Bar displacement is also one of major complications. To prevent this problem, one must chose correct bar length, place a bar under the deepest depressed point, use a stabilizer and fix a bar firmly to the ribs.[13-16] In older patients who lack of thoracic malleability, use of two bars provides much stability and superior cosmetic results.[11,17,18]

Among 16 patients receiving MIRPE, stainless bar and titanium alloy bar were used for the first 8 and the residual 8 patients, respectively. Nuss et al.[5] recommended stainless bar rather than titanium bar because of the stiffness and flexibility. We have been using dtitanium alloy bar since 2004 because of its improved profile compared to conventional titanium bar. Moreover, titanium bar has the following advantage: due to its light weight and thin plate, we can place the bar without standing out at the skin site where the bar was inserted even if a stabilizer is on. We have found no problems in patients with titanium alloy bar up to this time.

Most patients receiving MIRPE appeared to have more pain during the first week after operation. They usually required analgesic medications with high frequency in addition to the routine epidural analgesia.[1,12,19]

The present study suggests that SEMR and MIRPE will be most versatile methods for children among the 5 operation procedures because of minimum invasion and short hospital stay. Reports comparing SEMR and MIRPE indicate that MIRPE requires shorter operating time and less blood loss, while it provides more severe postoperative pain and longer limitation in activity than SEMR.[1] However, MIRPE has advantages that it has no incision of anterior chest wall and that it does not require resection of rib cartilages or osteotomy which may interfere with the rib growth plates in young children. If the same cosmetic outcomes can be obtained, it is important for patients and their parents to chose a method which makes no wound on the anterior chest wall. For this reason, patients and their family prefer MIRPE to other procedures at present. In the near future, more patients will reach the age to remove the bar and the long-term cosmetic outcomes of MIRPE will be assessed.

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