Surgical correction of the funnel chest deformity in children

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Abstract The aim of this study was to evaluate our results during and after the Nuss operation in children with pectus excavatum. We have performed the Nuss procedure in 128 patients with pectus excavatum since 2001, and 74 patients underwent bar removal. Of the 128 patients 96 were male and 32 were female; age ranged from eight to 21 years with an average of 13.8 years. In 46% of patients psychological reasons for operative treatment were dominant while in the other 54% of patients clinical signs were the indications. Complications in 128 patients included 36 pneumothorax, 28 of which resolved spontaneously. Postoperative pneumonia developed in six patients. In two patients we had infection of the implanted bar, and there were two patients with cellulitis. We had six patients with bar displacement and reoperation was needed. During the Nuss procedure we had one injury of the intercostal artery. We had pericardial tears in two patients without clinical significance. In two patients we had pericardial effusion six months after the Nuss procedure, requiring pericardiocentesis. In one patient we had fracture of the sternum. There were no complications following bar removal. After bar removal in 74 patients, 54 patients (72.9%) maintained excellent results with normal chest anatomy, good results were found in 16

patients (21.6%) with mild residual pectus and poor results in four patients (5.5%) with severe recurrence. Our experience with the Nuss procedure demonstrated excellent results with few minor complications.

Introduction

Pectus excavatum, produced by posterior depression of the sternum, is the most common congenital chest wall deformity [1]. Several theories explain the cause of pectus excavatum, but the aetiology remains obscure. Some authors believe that pectus excavatum may be due to overgrowth of costal cartilage, which displaces the sternum posteriorly [2–4]. Other theories are that abnormalities of diaphragm, rickets, elevated intrauterine pressure or intra-uterine compression to the sternum cause posterior displacement of the sternum [4]. A family history of pectus excavatum was present in 45% of our patients. In the literature patients with pectus excavatum, had a diagnosis of Marfan's syndrome in 3.1% and scoliosis was found in 29% of the patients [3]. In children with deformity of the chest wall it should be possible to remodel the changes [5]. Before 1998 surgical options for treatment pectus excavatum were operative treatment with skin incision, resection of costal cartilages, sternal wedge osteotomy and insertion of steel bar. The transverse incision beneath the breasts gives a good cosmetic scar. The lower four to five cartilages are removed and the perichondrium is left in place. Then a wedge osteotomy of the sternum is tailored correct to the defect. A pectus steel bar is inserted through the sternum [6]. After 1998 in children whose ribs and cartilages are still soft it was found to be unnecessary to make cartilage

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incisions, resections or sternal osteotomy. The Nuss procedure consisting of two lateral incisions on either side of the chest at the midaxillary line, was introduced. A separate small incision is required to allow direct thoracoscopic visualisation as the introducer and bar are passed under the sternum. Through small incisions the introducer is guided beneath the sternum to create a tunnel for the bar. A cotton tape guide is grasped by the introducer and pulled through the pathway that has been created. This guide is then used to pull through a metal bar, which has an appropriate shape for the type of the deformity. The bar is passed with convexity facing dorsally, along the curvature of the depressed sternum. The bar is then rotated 180 degrees around the axis of the hinge points thus elevating the depression. Both ends of the bar are then fixed with stabilisers and secured with sutures that resorb in about six months. In children under 12 years of age, one stabiliser was required and in older children bilateral stabilisers were used [7]. The Nuss procedure thus uses a retrosternal bar to repair pectus excavatum (Fig. 1).

Most of the patients present to our hospital after 15 years because the patients and families believe that the deformity will improve with age and surgical repair is dangerous, minimally effective and unnecessary. We had 19 patients who were followed-up before surgery for more than five years and showed no evidence of spontaneous regression of the deformity. All of these patients were younger than seven years of age and had no clinical symptoms. The ideal age for surgery is from seven to 14 years [7–9]. We believe also that whatever the possible

aetiologies of pectus excavatum spontaneous regression of the deformity is not possible regardless of the child's age. For children less than ten years of age with mild deformity, it may be possible, with exercise, to strengthen the muscles of the chest and make the deformity less pronounced. In older children and especially children over 14 years of age it is impossible to achieve spontaneous correction of depressions [8, 9].

Based on our experience and the literature, the Nuss procedure is a minimally invasive procedure with excellent postoperative results and few complications.

Patients and methods

We have performed the Nuss procedure in 128 patients with pectus excavatum since 2001, and 74 patients underwent bar removal. There were 96 male and 32 female patients and the gender ratio was 3:1. The age at surgery ranged from eight to 21 years (average 13.8 years). Out of 128 patients who had minimally invasive operations, 14 patients were under ten year old, 65 patients were between ten and 14 years old, 37 patients were between 14 and 16 years old, while 12 patients were 17 years old and older. The oldest patient was 21 years old.

Indications for operative treatment with the Nuss procedure were cardiac and pulmonary problems in 69 (54%) patients, and 59 (46%) patients had cosmetic and cosmetic-related psychological problems, progression of the deformity with other symptoms and Haller index greater than 3.25 [10]. We also recommended operative treatment when the Haller index was less than 3.25 only in children with severe cosmetic and cosmetic-related psychological problems. Most of the patients had an asthenic habitus and a narrow anterior-posterior chest diameter. All patients underwent cardiology and pulmonary examinations. Pulmonary evaluation and pulmonary function tests were done by a paediatric pulmonary physician and cardiology evaluation included examination by a paediatric cardiologist with ECG and echocardiogram. Clinical symptoms preoperatively were shortness of breath in 50 patients (39%), chest pain during exercise in 39 patients (30.4%), changes in ECG in 31 patients (24.2%), mitral valve prolapse in 18 patients (14%), functional heart murmur in 36 patients (28.1%), with the heart displaced to the left side in all 69 patients (100%) with clinical signs.

Asthma was present before operation in 14 patients (10.9%) and obstructive and restrictive changes in 65 (50.7%) patients. Cardiac compression was noted on echocardiogram or CT scan in 78 (60.9%) patients.

Among the cosmetic-related psychological problems the patients experienced were lack of motivation, constant

Fig. 1 Pectus bar in normal position

feeling of shame, high degree of self-awareness, constant fear of contacts, high degree of constant anxiety and latent aggressiveness.

CT scan was performed to assess the anatomy of the mediastinum and measure the Haller index which consists of dividing the transverse chest diameter by the anteroposterior diameter. An index of more than 3.2 has been correlated with severe deformity and requires operative treatment [10].

Prior to operation, epidural catheter and urinary bladder catheter were inserted because the early postoperative period is very painful and patients need intensive care. After operative treatment, intensive postoperative care was needed in all patients. The high epidural analgesia was safe and beneficial during the early period of pain treatment [11–13]. This catheter was needed for three to six days, with an average of four days. The urinary bladder catheter was in place for as long as the epidural catheter. During the Nuss procedure, 5-mm thoracoscopy was always performed through a skin incision on the right side. We performed video thoracoscopy to visualise of the mediastinal structures and the space between pericardium and sternum [14]. We always started the operative procedure on the left side where the introducer was entered into the thoracic cavity. The most dangerous part of the Nuss procedure is making a tunnel with the tip of the introducer between sternum and pericardium and heart [15–17].

After positioning both ends of the bar are fixed with stabilizers and secured with absorbable sutures to local muscle. In children under 12 years of age, one stabilizer was required and in older children bilateral stabilizers were used.

The follow-up period was between six months and five years (mean 3.6 years). We evaluated the results clinically and radiologically. The clinical criteria were the appearance of the chest after surgery. An excellent result was a normal chest without residual deformity, while a good result had mild residual deformity and a poor result, severe deformity. Radiological criteria for the success of the operation were the depth of the deformity before and after surgery. Before surgery the depth of the deformity varied from 3.1 cm to 6.2 cm (mean 4.5 cm). After the operation an excellent result had no depression or up to 1 cm, in a good result the deformity was no deeper than 2.5 cm and any measurement greater than 2.5 cm was considered a bad result.

Results

The length of hospital stay varied from seven to 24 days (average ten days). Blood loss was minimal (average 35 ml) and only one patient required blood transfusion for clinically significant bleeding due to injury of the intercostal artery. The epidural catheter was needed between three

and six days, (average of four days). The urinary bladder catheter was in place for as long as the epidural catheter.

Operative mortality was zero. No injury to underlying cardiac structures or the mamillary veins or arteries was noticed, nor was there postoperative pain in upper limbs or shoulders. All children with psychological symptoms before operative treatment had no significant problems after the Nuss procedure.

In the early postoperative period we had excellent results in 96 patients (75%), good result in 25 patients (19%) and poor in seven patients (6%). The same results were maintained over the follow-up period which was between six months and five years (mean 3.6 years). Ongoing monitoring continued for an average of 3.6 years, enabling a comparison immediately after surgery and after three years.

The complications were divided into early and late, minor and major. Early complications occurred immediately or in the first month after operative correction. Major complications were organ injuries or bleeding for which surgical intervention became immediately necessary. Early minor complications included pneumothorax with or without chest tube drainage, postoperative bar infections, pneumonia, bar displacement, pericardial tears without other complications and postoperative fracture of the sternum. Early major complications were organ injuries and bleeding requiring immediate surgical intervention. We had one major complication when we noticed bar displacement one month after reconstruction of the thorax and tried to exchange one bar with another through the same intrathoracic tunnel. We noticed haemothorax with laceration of the intercostal artery and urgent thoracotomy was done. Late complications occurred after the first month. Bar displacement was a major late complication in the repair pectus excavatum with the Nuss procedure. We also had pectus bar infection, cellulitis and stich infections. We diagnosed two cases of pericarditis six months after reconstructive treatment requiring pericardiocentesis with antibiotics [18, 19] (Fig. 3).

Complications occurred in 128 patients including 36 pneumothorax, two clinically insignificant pericardial tears without other complications, one patient had a fracture of the sternum, six had pneumonia, two developed pericarditis, one patient had haemothorax, two had bar infections and two with cellulitis. The 36 pneumothorax cases happened before removal of the thoracoscope at the end of the operative treatment; the lungs were ventilated with positive expiratory end pressure and pleural suction. In 28 patients the pneumothorax was small and resolved spontaneously and eight patients required a chest drain because the air shadow was greater than 2 cm [20, 21]. “Small” pneumothorax showed on X-ray as a small rim of the air around the lung of less than 2 cm. Injuries of the

pericardium originated from the tip of the introducer. One month after surgical procedure one patient felt strong pain in the chest. After radiographic evaluation a fracture of the sternum was found with no significant deformity or other clinical repercussion. Postoperative pneumonia in all patients responded to antibiotic and physical therapy. Only one patient had pleural effusion and chest tube drainage was necessary. In two patients with infection, the pectus bar was not removed because the infection resolved with conservative therapy. Cellulitis was defined as erythema and warmth which responded to antibiotics. No allergic reactions to titanium bars were noticed. In all patients with reoperation for bar displacement additional fixation was necessary (Fig. 2). In all cases of bar displacement rotation of the bar occurred along the axis of the hinge; the bar was replaced and secured with wire through the ribs. In one patient the bar was too weak and it was necessary to remove it and reimplant two bars. In two patients with Marfan's syndrome the sternum was not strong enough and collapsed above and below the metal bar. It was necessary to resect the cartilage and carry out sternal osteotomy (Table 1).

Comparing the results of the clinical picture before and after surgery showed a significant improvement. We compared 69 patients with clinical symptoms before and after surgery. Before surgery 50 patients had shortness of breath (72.5%), chest pain developed during exercise in 39 patients (56.5%), changes in ECG in 31 patients (44.9%), mitral valve prolapse was present in 18 patients (26%), and functional heart murmur in 36 patients (52.1%); shift of the heart to the left and cardiac compression were present in all 69 patients with clinical symptoms, and, in addition, asthma was present in 14 patients (20.2%). After surgery seven patients had shortness of breath (10.1%), eight patients had chest pain during exercise in (11.6%), changes in ECG

Fig. 2 Bar displacement

Fig. 3 Pericarditis

were present in 11 patients (11.6%), mitral valve prolapse in five patients (7.2%), functional heart murmur in seven patients (10.1%); shift of the heart to the left and cardiac compression were not present in any patients, and asthma was present in 14 patients (20.2%). After surgery in all patients with asthma the medication requirements decreased by about 30%. Comparing the number of patients and these percentages with clinical symptoms before and after surgery we observed significantly improved clinical status in all operated children. Evaluation of data was performed one year after surgery (Table 2).

In the same period since 2001, we had 74 patients who underwent bar removal. Bar removal is performed when permanent chest wall remodeling has occurred. After two years, the ends of the bar, the bar behind the sternum

Table 1 Complications among studied patients

Complications	Therapy	Number of patients
Pneumothorax	Resolved spontaneously	28
	Required thoracostomy	8
Pericardial tears	Without clinical signs	2
Pneumonia	Physical and antibiotic therapy	6
Pericarditis	Pericardiocentesis	2
Haemothorax	Required open thoracotomy	1
Bar infections	Conservative therapy	2
Cellulitis	Conservative therapy	2
Fracture of the sternum	Without significant clinical signs	1
Reoperation needed	Bar displacement	6
	Required two bars	1
	Marphan's patients-open surgery	2

Table 2 Clinical symptoms before and after surgery 69 patients

Symptoms	Before surgery		After surgery		McNemar chi-square
	N	%	N	%	
Scoliosis	22	31,8	22	31.8	–
Changes in ECG	31	44.9	11	15.9	$p=0.0000$
Shortnes of breath	50	72.5	7	10.1	$p=0.0000$
Obstructive/restrictive disorders	41	59.4	16	23.1	$p=0.0000$
Dyspnea/chest pain with exercise	39	56.5	8	11.6	$p=0.0000$
Asthma	14	20.2	14	20.2	–
The shift of the heart	69	100.0	0	0	–
Heart murmur	36	52.1	7	10.1	$p=0.0026$
Mitral valve prolapse	18	26	5	7.2	$p=0.1336$

and the stabilisers were usually surrounded by bone and connective tissue. The chest wall was in a new position with strong new bone behind the sternum making a firm chest wall. The time when the bar had to be removed was between two and four years and depended on the quantity of bone around the bar and stabilisers.

The procedure was done under general anaesthesia, no complications occurred and patients were able to leave hospital within one day after bar removal [12, 13]. Duration of operative treatment depended on quantity of the bone around the bar and stabilisers. When the ends of the bar and stabilisers are surrounded by dense bone and connective tissue, bar removal took over one hour.

Discussion

Since 2001 the minimally invasive procedure has become the standard in our hospital for the treatment of pectus excavatum. Indications for operative treatment with the Nuss procedure were cardio and pulmonary problems in 69 (54%) patients, and 59 (46%) patients had cosmetic and cosmetic related psychological problems. The preoperative diagnostic studies included cardiology and pulmonary examinations. Pulmonary evaluation and pulmonary function tests were done in all patients with clinical signs by a paediatric pulmonary physician and cardiology evaluation included examination by a paediatric cardiologist with ECG and echocardiogram.

After surgery, all children were treated in the intensive care unit. Postoperative pain was great and the best control of pain through an epidural catheter was in the intensive care unit. A well-trained team of doctors and nurses in the ICU provided excellent early postoperative recovery. Monitoring of laboratory findings, doses of analgesics and control of early complications is better in the ICU than in the general wards. Stay in the intensive care unit continued for as long as strong pain, an average of four days. After

removal of the epidural catheter, patients were transferred to the general wards. Our experience has shown excellent results in early postoperative treatment of funnel chest in the intensive care unit. The children were pain free and all early complications were observed and could be accessed at the time.

Our results in 128 patients showed that the procedure is effective and safe without many dangerous complications. Mortality was zero and we had only one patient requiring open thoracotomy for haemorrhage following damage to the intercostal artery. In all patients we had pneumothorax in the course of operation treatment because in all patients we used thoracoscopy with CO₂ insufflations. In eight patients the pneumothorax was bigger and chest tube drainage was necessary. In patients with bar infection and cellulitis, the pectus bar was not removed because the infection responded and resolved on conservative therapy [22–24]. In patients with bar displacement, reoperation was needed and it was necessary for additional fixation with wires through the ribs. In two patients with Marfan syndrome after removal of pectus bars, pectus excavatum was noticed and reoperations were necessary with the Sulamaa procedure [5]. We noticed two cases of pericarditis six months after treatment requiring pericardiocentesis with antibiotics [25, 26]. We were not sure of the cause of the pericarditis which developed slowly after the procedure and presume that the presence of the bar irritated the pericardium. The other minor complications resolved with conservative therapy. Comparing our results with results of other authors, we can conclude that

Table 3 Postoperative results after removed pectus bar in 74 patients

Results	Number of patients	Percent of patients
Excellent	54	72.9%
Good	16	21.6%
Poor	4	5.5%

our results do not differ significantly. Indications, age of children, cosmetic appearance and patient satisfaction, the percentage of improvement condition of the cardiorespiratory system, and the percentage of complications in the postoperative period were not statistically different [1, 3–5, 12, 16–21].

The best time for bar removal is after two to four years when permanent remodeling has occurred [27, 28]. In young children it is necessary to wait longer to remove the bar, until ossification around the bar occurs. In most cases removal of the bar was more difficult than the original procedure.

After bar removal in 74 patients, 54 (72.9%) had excellent results and maintained a normal chest. Good results were maintained in 16 patients (21.6%) with mild residual pectus and poor results in four patients (5.5%) with severe recurrence (Table 3). Comparing the early postoperative results with those after removal of the bars we saw that there was no significant difference. All patients were checked regularly, after a month, after three months, six months and finally just before removing the bar. After bar removal, patients were checked after one month and then once every year.

Comparing the results in the literature with ours we can state that the Nuss procedure is an effective method with excellent cosmetic results, low percentage of complications and excellent improvement in cardiopulmonary status [1, 3–5, 12, 16–21, 28, 29].

References

- Nuss D (2008) Minimally invasive surgical repair of pectus excavatum. *Semin Pediatr Surg* 17(3):209–217
- Nakaoka T, Uemura S, Yano T, Nakagawa Y, Tanimoto T, Suehiro S (2009) Does overgrowth of costal cartilage cause pectus excavatum? A study on the lengths of ribs and costal cartilages in asymmetric patients. *J Pediatr Surg* 44(7):1333–1336
- Kotzot D, Schwabegger AH (2009) Etiology of chest wall deformities—a genetic review for the treating physician. *J Pediatr Surg* 44(10):2004–2011
- Biniwale RM, Weinstein S, Boulauger SC et al (2009) Chest wall deformities. E-medicine. Medscape's continually updated clinical reference. Updated Jan 8
- Coelho Mde S, Silva RF, Bergonse Neto N, Stori Wde S Jr, dos Santos AF, Mendes RG, Fernandes Lde M (2009) Pectus excavatum surgery: sternochondroplasty versus Nuss procedure. *Ann Thorac Surg* 88(6):1773–1779
- Paltia V, Parkkulainen KV, Sulamaa M (1958/1959) Operative technique in funnel chest. *Acta Chir Scandinav* 116:90–98
- Nuss D, Kelly RE Jr (2008) Minimally invasive surgical correction of chest wall deformities in children (Nuss procedure). *Adv Pediatr* 55:395–410, Review
- Nuss D (2005) Recent experiences with minimally invasive pectus excavatum repair “Nuss procedure”. *Jpn J Thorac Cardiovasc Surg* 53(7):338–344
- Bohosiewicz J, Kudela G, Koszutski T (2005) Results of Nuss procedures for the correction of pectus excavatum. *Eur J Pediatr Surg* 15(1):6–10
- Nakagawa Y, Uemura S, Nakaoka T et al (2008) Evaluation of the Nuss procedure using pre- and postoperative computed tomographic index. *J Pediatr Surg* 43(3):518–521
- Butkovic D, Kralik S, Matolic M, Kralik M, Toljan S, Radesic L (2007) Postoperative analgesia with intravenous fentanyl PCA vs epidural block after thoracoscopic pectus excavatum repair in children. *Br J Anaesth* 98(5):677–681
- Futagawa K, Suwa I, Okuda T et al (2006) Anesthetic management for the minimally invasive Nuss procedure in 21 patients with pectus excavatum. *J Anesth* 20(1):48–50
- Cucchiario G, Adzick SN, Rose JB et al (2006) A comparison of epidural bupivacaine-fentanyl and bupivacaine-clonidine in children undergoing the Nuss procedure. *Anesth Analg* 103(2):322–327
- Saxena AK, Castellani C, Höllwarth ME (2007) Surgical aspects of thoracoscopy and efficacy of right thoracoscopy in minimally invasive repair of pectus excavatum. *J Thorac Cardiovasc Surg* 133(5):1201–1205
- Gips H, Zaitsev K, Hiss J (2008) Cardiac perforation by a pectus bar after surgical correction of pectus excavatum: case report and review of the literature. *Pediatr Surg Int* 24(5):617–620
- Castellani C, Schalamon J, Saxena AK, Höellwarth ME (2008) Early complications of the Nuss procedure for pectus excavatum: a prospective study. *Pediatr Surg Int* 24(6):659–666
- Leonhardt J, Kübler JF, Feiter J et al (2005) Complications of the minimally invasive repair of pectus excavatum. *J Pediatr Surg* 40(11):7–9
- Kim do H, Hwang JJ, Lee MK et al (2005) Analysis of the Nuss procedure for pectus excavatum in different age groups. *Ann Thorac Surg* 80(3):1073–1077
- Nuss D, Croitoru DP, Kelly RE Jr et al (2002) Review and discussion of the complications of minimally invasive pectus excavatum repair. *Eur J Pediatr Surg* 12(4):230–234
- Vegunta RK, Pacheco PE, Wallace LJ, Pearl RH (2008) Complications associated with the Nuss procedure: continued evolution of the learning curve. *Am J Surg* 195(3):313–316, discussion 316–317
- Fonkalsrud EW (2009) 912 open pectus excavatum repairs: changing trends, lessons learned: one surgeon's experience. *World J Surg* 33(2):180–190
- Van Renterghem KM, von Bismarck S, Bax NM et al (2005) Should an infected Nuss bar be removed? *J Pediatr Surg* 40(4):670–673
- Calkins CM, Shew SB, Sharp RJ et al (2005) Management of postoperative infections after the minimally invasive pectus excavatum repair. *J Pediatr Surg* 40(6):1004–1007, discussion 1007–1008
- Shin S, Goretsky MJ, Kelly RE Jr et al (2007) Infectious complications after the Nuss repair in a series of 863 patients. *J Pediatr Surg* 42(1):87–92
- Yang MH, Cheng YL, Tsai CS, Li CY (2008) Delayed cardiac tamponade after the Nuss procedure for pectus excavatum: a case report and simple management. *Heart Surg Forum* 11(2):129–131
- Barakat MJ, Morgan JA (2004) Haemopericardium causing cardiac tamponade: a late complication of pectus excavatum repair. *Heart* 90(4):22
- St Peter SD, Sharp RJ, Upadhyaya P et al (2007) A straightforward technique for removal of the subternal bar after the Nuss operation. *J Pediatr Surg* 42(10):1789–1791
- Krasopoulos G, Dusmet M, Ladas G, Goldstraw P (2006) Nuss procedure improves the quality of life in young male adults with pectus excavatum deformity. *Eur J Cardiothorac Surg* 29(1):1–5
- Kelly RE Jr, Cash TF, Shamberger RC et al (2008) Surgical repair of pectus excavatum markedly improves body image and perceived ability for physical activity: multicenter study. *Pediatrics* 122(6):1218–1222