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Original article

Minimally invasive repair of pectus excavatum using the Nuss technique in children and adolescents: Indications, outcomes, and limitations

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ABSTRACT

Background: Pectus excavatum (PE) is a common congenital deformity. The Nuss technique for minimally invasive repair of PE involves thoracoscopy-assisted insertion of a bar or plate behind the deformity to displace the sternum anteriorly. Our objective here was to clarify the indications and limitations of the Nuss technique based on a review of 70 patients.
Materials and methods: A retrospective review of children managed at two centres identified 70 patients who had completed their growth and had their plate removed. Mean age was 13.8 years (range, 6–19 years). The reason for surgery was cosmetic disfigurement in 66 (95%) patients. The original Nuss technique was used in 63 patients, whereas 7 patients required an additional sub-xiphoid approach. Time to implant removal ranged from 8 months to 3 years.
Results: The cosmetic outcome was considered satisfactory by the patients in 64 (91%) cases and by the surgeon in 60 (85.7%) cases. Major complications requiring further surgery occurred in 6 (8.5%) patients and consisted of haemothorax ($n = 2$), chest wall sepsis ($n = 2$, including 1 after implant removal), allergy ($n = 1$), and implant displacement ($n = 1$). Early or delayed minor complications occurred in 46 (65%) patients and resolved either spontaneously or after non-surgical therapy.
Discussion: The minimal scarring and reliably good outcomes support the widespread use of the Nuss technique in children and adolescents. Our complication rates (minor, 65%; and major, 8.5%) are consistent with previous publications. In our opinion, contra-indications to thoracoscopic PE correction consist of a history of cardio-thoracic surgery and the finding by computed tomography of a sternum-to-spine distance of less than 5 cm or of sternum rotation greater than 35°. In these situations, we recommend a sub- and retro-xiphoid approach to guide implant insertion or a classic sterno-chondroplasty procedure.
Level of evidence: Level IV, retrospective descriptive cohort study.

1. Introduction

Pectus excavatum (PE) is a common congenital deformity first described in 1594 [1,2]. Asymmetrical rib cartilage growth with overgrowth of some of the ribs is the accepted pathophysiological mechanism. PE is idiopathic in 50% of cases. A tiny minority of PE cases occur as part of Marfan syndrome (5%) or Ehlers-Danlos syndrome (1%) [3].

The classic surgical technique for correcting PE is sterno-chondroplasty [4–7]. However, the scars left by this procedure limit its ability to provide satisfactory outcomes when the reason for surgery is cosmetic disfigurement. Minimally invasive repair of PE (MIRPE) as developed by Nuss is a simpler procedure that does not require cartilage resection and leaves only tiny scars. MIRPE consists in inducing remodelling of the growing chest wall to a normal shape by inserting one or two metallic bars behind the sternum under thoracoscopic guidance (Fig. 1) [8–10]. The malleability of the chest wall during the growth period allows stable correction of the deformity, and the implants can be removed after 2–3 years. Several types of complications have been described since the introduction of MIRPE.

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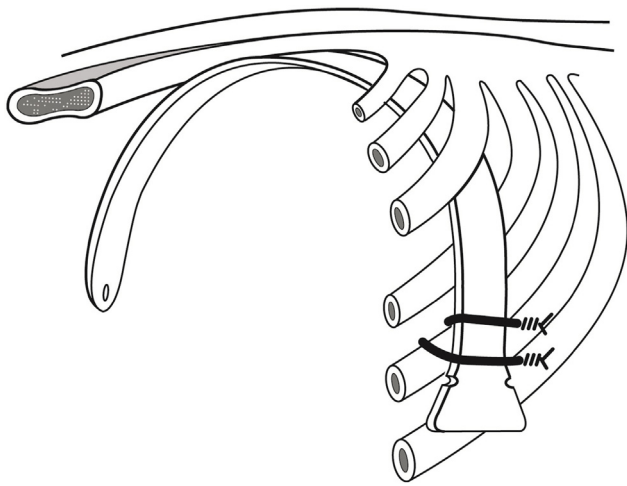E-mail addresses: redakabbaj@hotmail.com, reda.kabbaj@trs.aphp.fr (R. Kabbaj).

Fig. 1. Principle of pectus excavatum repair using a modified retro-sternal bar. The right end is broadened to improve stability. The notches on the sides secure the metal wires to the bar.
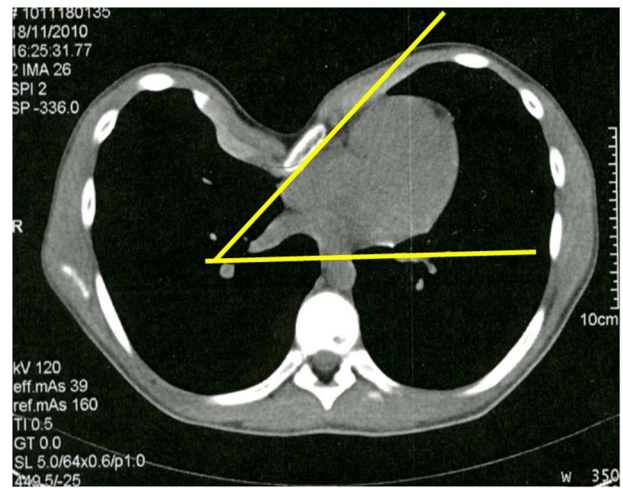

Fig. 2. Among computed tomography parameters, we believe the sternal rotation angle is important. A value greater than 35° contra-indicates thoracoscopic repair.
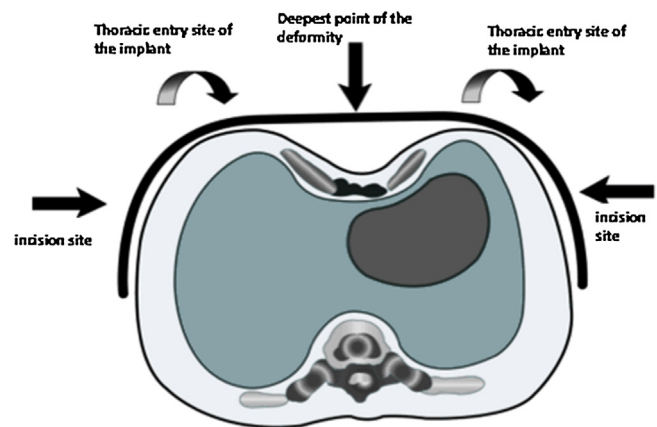
We hypothesised that improved patient-selection for MIRPE would clarify the indications and shed light on the limitations of this procedure. Based on a retrospective case-series of 70 patients who had achieved skeletal maturity and had their implants removed, we evaluated the outcomes and patient-selection criteria of MIRPE.

2. Material and method

2.1. Patients

We retrospectively reviewed the records of patients who underwent surgical PE repair between February 2004 and December 2011 at the Marseille university hospital and Lyon university hospital. Among these patients, 25 were included in a previous study [3]. Inclusion criteria were achievement of skeletal maturity and implant removal at least 1 year earlier.

We identified 70 patients, 52 males and 18 females, with a mean age at the first visit of 13 years (range, 2–19 years) and a mean age at surgery of 13.8 years (range, 6–19 years). The deformity was symmetrical and located on the midline in 53 patients. Other abnormalities consisted of scoliosis in 9 patients, including 8 with idiopathic scoliosis, and Marfan syndrome in 5 patients. A history of thoracic surgery was noted in 4 patients (2 each with heart and lung surgery), a history of lung disease in 5 patients (asthma, spontaneous pneumothorax, and exertional dyspnoea), and a history of heart disease in 4 patients (moderate aortic ectasia or mitral valve prolapse). Heart surgery was not deemed necessary in these patients. Two patients each had a sibling who had had surgery to repair PE.

All our patients underwent at least two outpatient evaluations before surgery. The reason for surgeon referral was cosmetic disfigurement alone in 66 (95%) patients and clinical respiratory symptoms in 4 (5%) patients, including 3 with Marfan syndrome and 1 with Elhers-Danlos syndrome. In 23 patients, the anaesthesiologists requested pulmonary function testing (PFT), which showed abnormalities in 7 patients including 1 with severe restrictive and obstructive ventilatory impairments. Echocardiography was performed in 20 patients; this investigations was done routinely early in our experience but was subsequently reserved for patients with Marfan syndrome. Patent foramen ovale was not noted in any of these 20 patients but was not sought using specific tests. Computed tomography (CT) of the chest was obtained routinely before surgery to assess the characteristics of the deformity and to look for CT indicators of severe PE. Thus, the distance from the posterior

aspect of the sternum to the anterior aspect of the vertebral body at the site of greatest deformity depth (sternum-to-vertebra distance, SVD) was measured and found to range from 16 to 75 mm. The most widely used indicator of PE severity is the Haller index computed as the transverse chest diameter at the site of greatest deformity depth divided by the SVD [9]. Haller index values in our patients ranged from 2.2 to 6.8 mm. We defined a third parameter, the sternum rotation angle (SRA), as the angle formed by the horizontal plane and the transverse axis of the sternum at the site of greatest deformity depth (Fig. 2). The SRA ranged from 0° to 50° (Fig. 1).

2.2. Operative technique

The procedure was consistently performed by two senior surgeons (either two orthopaedic surgeons or one orthopaedic surgeon and one chest surgeon). In 63 patients, MIRPE was performed under right thoracoscopic guidance, as initially described by Nuss [7,10]. Implant size and shape were selected to match the configuration of the chest wall in each individual patient. The implants were secured to the chest wall with metallic suture (Medicalex®, Bagneux, France) (Figs. 3 and 4). Thoracoscopy was not used in 7 patients, including 3 with severe PE and 4 with a history of heart or lung surgery. In these severe forms, a 3-cm sub- and retro-xiphoid approach was required to lift the sternum and to release any adhesions between the sternum and pericardium (Fig. 5A and B). In 2
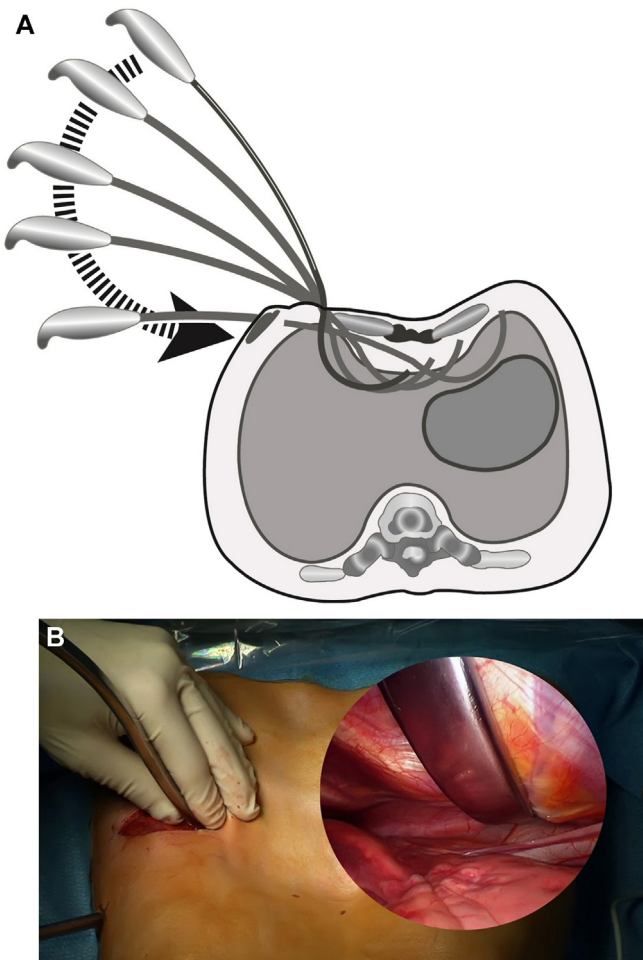

Fig. 3. Position of the incisions and of the entry and exit points of the bar into the thorax.

Fig. 4. The guide must be kept in contact with the sternum and sterno-costal cartilages. Thoracoscopic guidance is used to identify the plane of passage between the pericardium and sternum.

Fig. 6. A. Asymmetric and deep deformity. The sterno-vertebral distance was less than 5 cm and the sternal rotation angle was greater than 30°. A sub- and retroxiphoid approach was used. B. Postoperative computed tomography.

patients, the sterno-costal cartilages of the lowest ribs were cut to allow safe implant insertion under digital guidance. Thoracoscopy was not required in this variant of the procedure (Fig. 6A and B).

A chest drain was used in 36 patients, for a mean duration of 1.5 days (range, 1–5 days). Early in our experience, we routinely drained the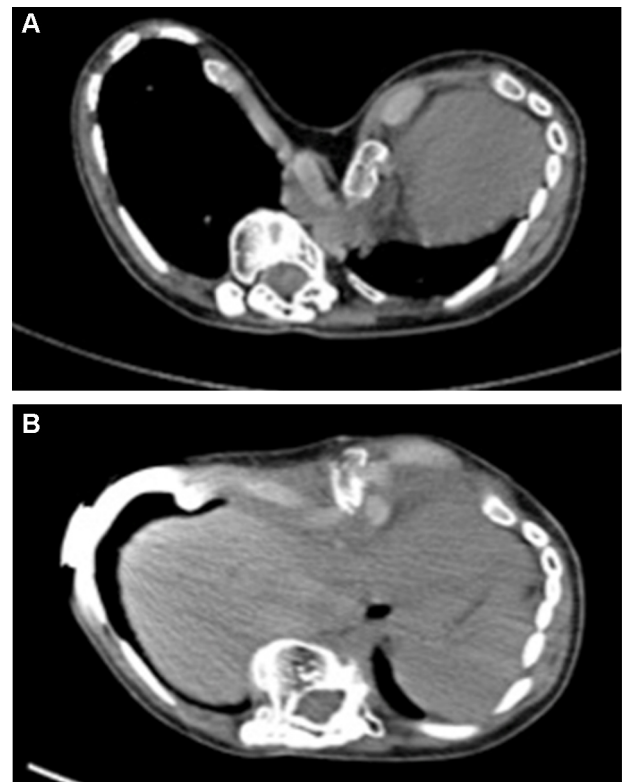 right haemothorax, whereas later on drainage was used in only 1 of 7 patients. Thoracic epidural analgesia was performed for postoperative pain control in 28 (40%) patients. A step 3 analgesic via a programmable pump (patient-controlled analgesia) was used routinely for 4–5 days.

Ambulation was started on the 4th postoperative day. Physiotherapy was not prescribed routinely, but an intensive strength-training programme was recommended after the 2nd month in patients older than 15 years of age. Resumption of sports was allowed 2 to 3 months after the procedure.

The implant was removed after 2–3 years if well tolerated by the patient. Implant removal was performed with the patient supine, through the same incisions. The metallic cerclage wires
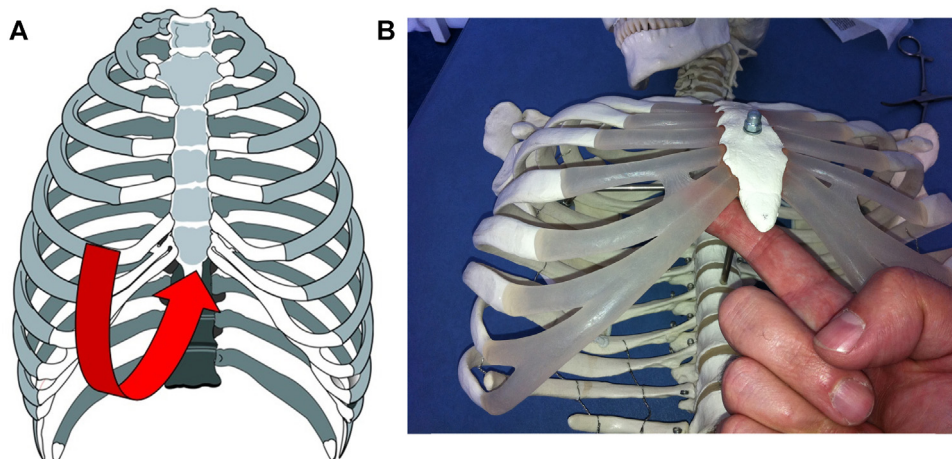

Fig. 5. A. A vertical incision at the level of the xiphoid allows passage of a finger then of a retractor under the sternum, thereby ensuring safe implant passage between the sternum and pericardium under digital guidance. B. Lateral detachment can be performed until the mediastinal pleura is reached.

were removed and dedicated tools were used to straighten the implant.

2.3. Outcome assessment

The patients were re-evaluated during the immediate postoperative period then 1 and 3 months later and finally every 6 months. The cosmetic outcomes were graded as described by Wurtz et al. [7], with the addition of overcorrection to the failure grade. A self-evaluation by the patient and an evaluation by one of us were performed in every case. At last follow-up, imaging studies were obtained in only 2 patients, who underwent postoperative CT to look for complications.

We used the following grading system to evaluate physical performance:

- very substantial improvement, with the ability to broaden the scope of sporting activities;
- moderate improvement with no substantial change in sporting activities;
- no change;
- diminished physical performance.

Immediate, early, and delayed postoperative complications were classified as major or minor as described by Castellani et al. [11]. No patients underwent PFT more than 2 years after surgery.

3. Results

Mean follow-up was 61 months (range, 26–107 months). Mean operative time was 85 minutes (range, 45–200 minutes) and mean hospital stay length for the repair procedure was 7.2 days (range, 5–12 days). A single bar was sufficient in 54 patients, whereas 16 patients required two bars.

The implant was removed in all 70 patients, after a mean of 28 months (range, 8–51 months). For this procedure, mean operative time was 37 minutes (range, 15–140 minutes) and mean hospital stay length was 1.7 days (range, 1–3 days).

Intra-operative complications occurred in 2 patients: 1 patient had a pericardial contusion with no clinical effects and the other a heart rhythm disorder that resolved immediately with ephedrine therapy.

Of the 44 early complications, 3 (3/70, 4.3%) were major and 41 (41/70, 59%) were minor (Table 1). Of the 8 delayed complications, 3 (3/70, 4.3%) were major and 5 (5/70, 7.1%) were minor (Table 2).

Table 3 reports the cosmetic outcomes as evaluated by the surgeons and patients.

Function as assessed by the patients was very substantially improved in 8 cases, moderately improved in 22 cases, and unchanged in 40 cases. No patient reported diminished physical performance.

Table 1
Early major and minor complications.

Major ($n = 3$)	Minor ($n = 41$)
2 pleural effusions, drained on days 4 and 6, respectively	37 cases of pneumothorax < 15 mm with spontaneous resolution
1 acute sepsis treated with surgical drainage and antibiotic therapy	1 pericardial effusion that resolved with NSAID therapy
	1 staphylococcal chest wall sepsis treated with antibiotics
	2 cases of pneumonia treated with antibiotics

Table 2
Delayed major and minor complications.

Major ($n = 3$)	Minor ($n = 5$)
1 secondary post-traumatic displacement of the implant (surgical revision)	5 patients with pain at the tip of the implant that resolved after implant removal
1 chest wall sepsis after implant removal	
1 premature implant removal due to an allergic reaction	

Table 3
Cosmetic outcomes as evaluated by the patients and surgeons.

Cosmetic outcome n of patients	Evaluated by the patient	Evaluated by the surgeon
Excellent	38	34
Good	26	26
Fair	5	9
Failure	1	1

4. Discussion

We report on a retrospective case-series of 70 patients who underwent surgical PE repair according to standardised principles and who were re-evaluated after achieving skeletal maturity. The main weakness of our study is the absence of objective criteria for quantifying the degree of correction. However, this weakness exists for all studies of PE repair. The radiation exposure required for CT and high cost of MRI preclude the use of these imaging techniques merely for purposes of clinical evaluation. We are working on non-invasive optical measurement methods for objectively assessing the degree of correction [12].

Patient satisfaction with the cosmetic outcome in our study was similar to that reported in other published case-series studies [8,11,13].

Our data on complications are also in line with earlier reports. We recorded minor complications in 65% of patients and major complications in 8.5% of patients. These numbers should be interpreted carefully, with attention to the fact that only 2 patients required further surgery, for chest wall sepsis, and 2 others secondary chest-tube placement to drain reactive effusions. Late revision surgery was required in 1 patient whose implant was displaced during a fall.

Earlier data on fatal or major complications indicate a close association with a history of cardio-thoracic surgery and with the severity of the deformity [14–16]. None of our patients experienced fatal complications or major cardiopulmonary complications. In 7 patients, we used a sub- and retro-xiphoid approach to guide implant insertion behind the sternum. In very severe deformities, the last rib cartilages can be cut to release the sternum (Fig. 7). Bilateral thoracoscopy has been suggested in this situation but we have no experience with this method, which our anaesthesiologists deem inadvisable [17]. The use of a retractor to lift the sternum is a modification that closely resembles the one used in our study and that seems to meet the same efficacy criteria [18].

Surgery performed for cosmetic purposes in minor patients may raise ethical questions. Nevertheless, PE has a profound impact on body image that in turn adversely affects participation in physical activities and quality of life [19–21]. In addition to these cosmetic considerations, recent work by Nevière et al. [22,23] demonstrated statistically significant improvements in cardio-circulatory function during exercise in adults after PE repair. These improvements were related to gains in inspiratory muscle function after surgery.

Sterno-chondroplasty techniques exhibit the disadvantages shared by all open-surgery procedures. They should not be used during the growth period, as they may impair the remaining

Fig. 7. A. Clinical appearance before surgery in a child with Marfan syndrome. B. Appearance after surgical correction of the pectus excavatum and scoliosis.

growth potential of the thorax. We reserve sterno-chondroplasty for markedly asymmetric PE in patients late during puberty. Sterno-chondroplasty is probably a procedure of choice in adults. Conservative treatment using a vacuum bell has produced good outcomes [24]. However, none of the published case-series studies was done after skeletal maturity was achieved. Corrective procedures that involve the use of rib clips necessarily block the residual growth of the thorax. In addition, as the clips are fixed elements attached to the mobile chest wall, they are vulnerable to rupture, most notably in adolescent athletes [25]. Silicone prostheses can be implanted to fill the depression but may migrate in the long term. The need to leave these implants in place in the long term leads us to prefer other treatment options in young patients [26].

MIRPE is an interesting treatment option in children. The risk of major cardiopulmonary complications can be markedly diminished by using a sub- and retro-xiphoid approach. We believe the main limitations to thoracoscopy-assisted PE repair are a history of cardio-thoracic surgery and the finding by CT of an SVD lower than 5 cm or of an SRA greater than 35°. Finally, marked chest wall asymmetry contra-indicates MIRPE, and a better option in this situation is sub-perichondral sterno-chondroplasty at the end of puberty.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

Acknowledgements

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