Experience in minimally invasive Nuss operation for 406 children with pectus excavatum

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Background: **This study was to investigate the advantages of thoracoscopy-assisted minimally invasive Nuss operation for the treatment of pectus excavatum (PE) in children.**

Methods: **A total of 406 patients with PE (female: 93; male: 313) with an average age of 6.8 years (range: 3.5-17.5 years) were included in this study. Associated diseases included congenital heart disease in 9 patients and congenital pulmonary cyst in 2. The Haller index of the patients ranged from 3.35 to 7.23, with an average of 5.17±1.64. Minimally invasive Nuss operation was performed for all the patients.**

Results: **The operations were performed successfully and no operative mortality occurred. The average blood loss during the operation was less than 10 mL and the operating time ranged from 30 to 85 minutes with an average of 45 minutes. The length of hospital stay ranged from 5 to 9 days with an average of 7 days. Struts were implanted in 12 (3.0%) of the 406 patients. Injury of the pericardium occurred in 1 patient during the operation. Early post-operative complications occurred in 9 patients with pneumothorax and 6 patients with pleural effusion, which were cured by puncture or drainage. Poor wound healing occurred in 4 patients (1.0%) and was cured by nutritional support. During a 3-month to 6-year follow-up, 2 patients had scoliosis and 3 patients had displacement of the strut, which was cured by a second Nuss operation. Allergy occurred in 2 patients: the symptoms were improved in 1 patient after conservative treatment, but the strut was removed in advance due to allergy in the other patient. Totally 154 patients (40.0%) underwent operation for strut removal. Excellent repair results were achieved in 387 (95.3%) patients, good repair results in 12 (3.0%), and fair results in 7 (1.7%).**

Conclusions: **Thoracoscopy-assisted Nuss operation has many advantages including small and masked incision, short operative time, minimal blood loss, fast recovery, less trauma, and satisfactory outcomes of repair. Nuss is a safe and reliable technique for repair of PE.**

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Introduction

Pectus excavatum (PE) is one of the common thoracic developmental malformations, with an incidence rate of 0.1%-0.3% and a male to female ratio of about 4:1.[1,2] In 1998, Dr Donald Nuss proposed minimally invasive repair of pectus excavatum, without resection of osteochondrous parts of the anterior chest wall. The operation was also termed as Nuss operation, resulting in an era of minimally invasive treatment for PE.[1] The key procedure of Nuss operation is the implantation of a suitable metal strut to lift the sternum. Nuss operation does not need to cut off the cartilage of the anterior pectus and the strut can be kept within the body for 2-4 years or longer if necessary.[3] This operation has been widely carried out in China. Since 2004, we have performed thoracoscopy-assisted Nuss operations for 406 patients with PE and achieved satisfactory results.

Methods

Clinical data

From June 2004 to February 2011, 406 patients with

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congenital PE (male: 313; female: 93) with an average age of 6.8 years (range: 3.5-17.5 years) were admitted to our Department. Eleven patients (2.7%) were found to have associated malformations including congenital ventricular septal defect (5 patients), atrial septal defect (2), ventricular septal defect with right ventricular dual-chamber (1), Tetralogy of Fallot (1), and congenital lung cyst (2). Most of these patients had visited hospitals because of the abnormal appearance of the pectus wall. Ten patients (2.5%) had symptoms of recurrent respiratory tract infection and 7 (1.7%) had incomplete right bundle branch block revealed by electrocardiography. Before operation, the condition was assessed by lateral chest X-ray and CT scan. The Haller index of the patients ranged from 3.35 to 7.23, with an average of 5.17±1.64 (Table 1). Because repair of pectus excavatum was cosmetic, informed consents were obtained from parents of the patients before the operation. This study was approved by the Ethics Committee of our hospital.

Nuss operation

The operation was performed by tracheal intubation combined with intravenous anesthesia. The patient was placed in a supine position and the sites of the operation included the lowest concaves of the sternum, the highest points of both ribs and the cutting area of the left and right pectus. The pectus wall was measured to select the strut with an appropriate length. Before skin incision, the template strut was applied. A 1.5-2 cm transverse incision was made between the axilla anterior and backward lines on both sides of the pectus wall. A thoracoscope sheath was placed (5.0 mm depth; 0° or 30° angle) between the first and second ribs below the right incision to monitor the operation. Under anesthesia, CO_2 gas with a pressure of 6.0-10 mmHg and a speed of 2.0-2.5 L/min was injected to induce a collapse of the lung. With continuous monitoring under a thoracoscope, the extension clamp was slowly moved from the right incision along the pre-selected intercostal space to the collapsed area of the sternum. The clamp was moved over the mediastinum behind the sternum toward the left incision. The strut was connected to the extension clamp and the convex side of the strut was pulled over the backside of the sternum. When the strut was in the position, it was turned over (180°). The sternum and anterior pectus wall were protruded in an expected shape. The strut on one side was invaginated in the holder and the holder was sutured to the rib periosteum. Subsequently, the holder, pectus wall and strut were sutured together. Under a thoracoscope, the strut was placed in a satisfactory position without obvious bleeding. A water seal pipe was connected to the vent of the thoracoscope sheath. After lung expansion and air exhaustion, the thoracoscope sheath was pulled out. If necessary, a pectus drainage tube was placed. At last the muscle and skin were sutured. After operation, the patient was sent to the intensive care unit for regular analgesic and anti-infective treatment. If there was a flat pectus or the concaves were widely present in PE patients, 2 struts might be considered for implantation during the operation. Except one patient undergoing stage operation for Tetralogy of Fallot, the other patients underwent Nuss operation and congenital heart disease repair at the same time.

Table 1. Basic data from the 406 patients with pectus excavatum before surgery

Variables	*n* (%)
Sex	
Male	313 (77.1%)
Female	93 (22.9%)
Age, mean (range)	6.8 y (3.5-17.5 y)
Mean Haller index (range)	5.17±1.64 (3.35-7.23)
Associated malformations	11 (2.7%)
Congenital ventricular septal defect	5 (1.2%)
Atrial septal defect	2 (0.5%)
Congenital lung cyst	2 (0.5%)
Ventricular septal defect with right ventricular dual-chamber	1 (0.2%)
Tetralogy of Fallot	1 (0.2%)

Evaluation of Nuss operation

Currently there have been no unified criteria for evaluating the outcomes of Nuss operation. The outcome of the operation can be divided into 4 grades:[4] excellent: symmetric correction and no concaves of residual sternum; good: symmetric correction or no symmetric correction and concaves of the sternum after operation less than 20% of those before operation; fair: sternum residual concaves after operation 20%-50% of those before operation; and poor: sternum residual concaves after operation more than 50% of those before operation.

Results

Nuss operation was successfully performed in all the 406 patients. Blood loss during the operation was less than 10 mL on average and postoperative pain lasted for 4-7 days. The operative time was 45 minutes on average (range: 30-85 minutes) and the postoperative hospitalization was 7 days (range: 5-9 days). Twelve (3.0%) of the PE patients were implanted with 2 struts for flat pectus or wide concaves. One patient had injury of the pericardium, which was immediately demonstrated by a thoracoscope, thus preventing bleeding and severe cardiovascular damage. A drainage tube was placed in the thoracic cavity of

7 patients (1.7%) after operation. Early postoperative complications included pneumothorax (9 patients) and pleural effusion (6). In the 9 patients, 4 were cured by air extraction with puncture and 5 by closed thoracic drainage. The 6 patients, 2 with pleural hemorrhage and 4 with non-hemorrhagic pleural effusion, were cured after puncture or drainage. Poor wound healing occurred in 4 patients (1.0%), who had a pectus index greater than 7 and a poor nutritional status. After symptomatic and supportive treatment, the 2 patients with pleural hemorrhage were cured. All patients were followed up for 3 months to 6 years. Five patients (1.2%) had a second Nuss operation because of scoliosis caused by severe pain in 2 patients and displacement of the strut in 3 patients. After the second Nuss operation, symptoms disappeared in the 5 patients. Two patients (0.5%) were re-hospitalized at 10 months after the operation because of allergy and skin ulcers in the incision sites. After conservative treatment, the symptoms of one patient were relieved, but the strut was pulled out in advance for the other patient. In all, 154 (40.0%) patients had the strut removed. A total of 387 patients (95.3%) showed excellent results, 12 (3.0%) showed good results, and 7 (1.7%) had fair results. A 14-year-old female patient with PE was cured satisfactorily (Fig.)

Discussion

Treatment of children with PE aims to improve cardiopulmonary function, relieve psychological stress, and prevent such complications as scoliosis and flat pectus through correcting the malformations. There are 2 traditional surgical methods for the repair of PE: Wada sternal turnover operation and Ravitch operation. The Wada sternal turnover operation has been abandoned for large damage and ineffective repair.[5] The Ravitch operation has a 10 cm surgical scar left in the chest, which causes complications such as flat pectus, skin perforation due to the movement of an internal fixer (e.g., Kirschner needle), and pericardium injuries. These complications ultimately result in the failure of the repair.[6] With the development of endoscopic techniques, Nuss first introduced thoracoscopy-assisted minimally invasive repair for PE (Nuss operation) in 1998.[1,7] Because of its simplicity, fewer complications, less pain and satisfactory results, Nuss operation has been well accepted by both surgeons and patients.

Because of physiological characteristics of children, thoracoscopy-assisted Nuss operation is appropriate specifically for 3-7 years old patients. First, impairment of the cardiopulmonary function is not severe in this age group. Cardiac function can be rapidly recovered and pulmonary function gradually recovered after Nuss operation for PE. Second, the impact of the disease on pre-school children is not severe as psychological cognitive ability is increased with age. Psychological impairment will be rapidly forgotten after correction of the malformation and thus there are no severe outcomes. Third, complications of PE like scoliosis, asymmetric funnel chest and sternum torsion have not yet been found in this age group. However, in

Table 2. Characteristics of the 406 patients undergoing Nuss operation for pectus excavatum

Variables	*n* (%)
Average blood loss	10 mL
Average duration of postoperative pain	4-7 d
Average operative time	45 min (range: 30-85 min)
Average postoperative hospitalization	7 d (range: 5-9 d)
Drainage tube placement	7 (1.7%)
Early postoperative complications	
Pneumothorax	9 (2.2%)
Pleural effusion	6 (1.5%)
Poor wound healing	4 (1.0%)
Second Nuss operation	5 (1.2%)
Re-hospitalization	2 (0.5%)
Strut removal up to present	154 (40.0%)
Outcome of the operation	
Excellent results	387 (95.3%)
Good results	12 (3.0%)
Fair results	7 (1.7%)

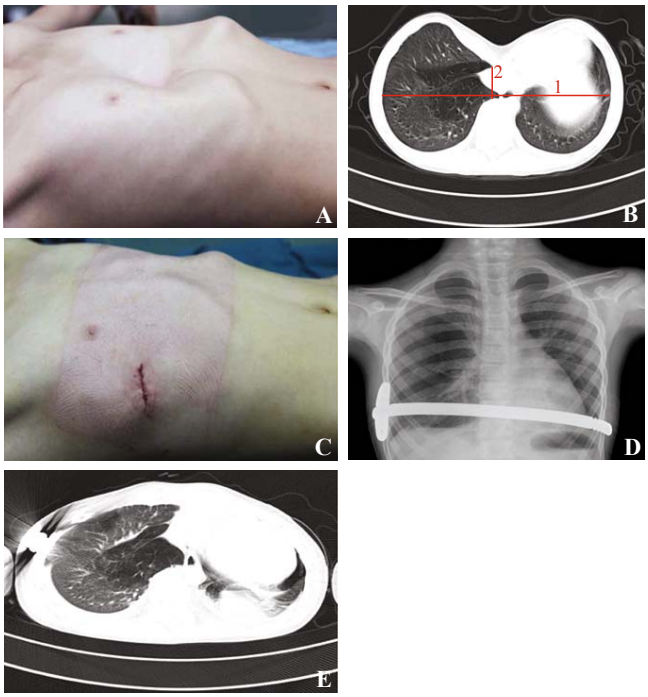

Fig. A: A 14-year-old female patient with pectus excavatum; **B:** CT scan of the chest of the patient. The chest Haller index is obtained by dividing measurement 1 by 2; **C:** Immediate postoperative appearance of the chest of the 14-year-old patient, with the small band-aid covering the right lateral chest wall incision. Chest radiography (**D**) and CT scan (**E**) of the chest of the same patient obtained after surgery.

more than 20 years practice, age for Nuss operation has been increased to adults.[8] Thoracoscopy-assisted Nuss operation should meet two or more indications as follow:[9,10] (1) Haller index greater than 3.25 shown by CT; (2) a restrictive or obstructive airway disease shown by examination of pulmonary function; (3) incomplete right bundle branch block and mitral valve prolapse demonstrated by electrocardiography and echocardiography; (4) malformation progress with obvious symptoms; (5) malformation and psychological problems intolerable to children; (6) recurrence of PE after Ravitch, sternum turn-over and Nuss operations. In addition, Nuss operation is the best choice for patients with extensive symmetrical pectus excavatum, especially for those complicated with flat chest.

The following points should be carefully considered for Nuss operation. First, the types of concaves in PE patients should be determined before operation and personalized struts should be used. Second, a laparoscope should be used during the operation. The strut is guided by a thoracoscope through the areas with fewer vessels. It should be determined whether there are blood vessels or pericardium tissue wrappings. After implantation of the strut, examinations are required to ensure no appearance of bleeding. Third, the introducer should be close to the rib and the backside of the sternum when it is performing guided penetration. The introducer should be lifted when it is moving from the left to the right side in order to minimize possible damage to the heart and pericardium. Fourth, supporting point normally chooses the lowest site of concaves in the sternum or the flat site on the rear part of the sternum. The position of the strut should not be too low in order to avoid the diaphragm or abdominal organ injuries. Fifth, the curvature of the bending strut should not be too close in order to leave some spaces for the development of the patient and prevent the oppression of ribs and intercostal vascular injuries. Finally, after the operation is finished, the lung should be fully expanded to release the air completely. The chest drainage tube could be placed in an unconventional manner.

The short-term complications for thoracoscopy-assisted Nuss operation include injury of pericardium, pneumothorax, subcutaneous emphysema, hemothorax, pleural effusion and pain, etc. Displacement of the strut is the main long-term complication, while allergy is rare.[11] After timing and symptomatic treatment of the early complications, most patients can be cured. In contrast, displacement of the strut is the main cause of PE recurrence. In this study, 3 patients had displacement of strut and required a second Nuss operation. Therefore, it is important to select the appropriate place to anchor the strut and the method for thoracic wall fixation. An appropriate strut point should be chosen between the lowest point of the concaves and the highest point of both thoraxes. The best choice is that the strut can not only prop up the bottom of the concaves, but also effectively depress the convex of both thoraxes. For those with large areas of concaves and flat bottoms, the bracket point can be selected at the bottom of the funnel. For those patients with small and deep funnels, the area for the strut to contact the sternum should be appropriately increased in order to enhance the stability of an implanted strut. If the strut is supported on the xiphoid plane with greater flexibility, it is easy to cause the displacement of the strut. If necessary, 2 or more than 2 struts need to be implanted. In this study, 2 struts were implanted for 12 patients with wide concaves to effectively prevent recurrence. In addition, application of bilateral fixation and improvement of the strut fixation approaches can effectively enhance the stability of the strut. For example, Hebra et al[12] used "3-point fixation system" and Uemura et al[13] used stainless steel wire to directly bind the ribs. However, it should be particularly careful to protect the intercostal muscle when the strut was fixed with the thorax wall. Extensive suturing of the intercostal muscle may decrease the stability of strut and increase the incidence of strut displacement.

In addition to the prevention of strut displacement, attentions should also be paid to the management and guidance of the patient after Nuss operation. Patients should maintain in a supine position. If possible, they should wear position rectification vest to keep the chest straight. During the first 6 weeks after leaving the hospital, the patients should not bend, twist or roll. Extreme exercises should also be avoided within 2 years of operation to prevent strut displacement. For older children, sustained and severe postoperative pain after Nuss operation may result in complications such as scoliosis and bar displacement. Therefore, the strut has to be pulled out shortly after the operation, leading to the recurrence of PE. Adequate pain management should be given to the patients undergoing Nuss procedure to prevent postoperative respiratory complications and ensure an uneventful recovery.[14] Analgesia after Nuss operation and psychological counseling are especially important. In our department regular management of postoperative pain is advocated, and for some old children, controlled analgesia is used.

In summary, thoracoscopy-assisted minimally invasive Nuss operation has the following advantages: small and hidden incisions, shorter operative time, less bleeding, less trauma, rapid recovery and satisfactory repair outcomes. Nuss operation is safe, reliable and worth using clinically.

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Competing interest: None.

Contributors: Yu JG and Shi Z proposed the study and wrote the first draft. Xu WZ analyzed the data. All authors contributed to the design and interpretation of the study and to further drafts. Shu Q is the guarantor.

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