An effective method for surgically repairing pectus excavatum without removing the costal cartilages was described by Nuss in 1998. With this minimally invasive technique, 2 small incisions are made on the lateral chest wall, and a convex steel bar, contoured to the patient's chest, is inserted under the sternum, with the convex surface facing posteriorly. The bar is then rotated 180° so that the convex surface elevates the sternum and corrects the pectus deformity. The bar is removed after 2 years, when permanent remolding has occurred. The results have been good to excellent. The procedure offers several advantages over pectus repair in which cartilage is removed, with or without strut support. It is easier to perform, avoids having to make an anterior chest incision, returns the patient to full activity sooner, preserves elasticity of the chest, and does not retard chest wall growth. Currently, the ease of the Nuss technique makes it the procedure of choice for surgical repair of pectus excavatum. Furthermore, its long-term benefits may be even greater. By preserving the costal cartilages, the Nuss procedure maintains chest elasticity and chest wall growth. Thus, it avoids the restrictive effects associated with costochondrectomy and has the potential to improve both cardiac and pulmonary functions.

In April 1998, Nuss reported an innovative surgical technique to correct pectus excavatum that did not involve costal cartilage removal or sternal osteotomy (1). Instead, a convex, stainless steel bar is inserted through the thoracic cavity to move the sternum forward. The genesis of this technique was Nuss’ observations that various skeletal deformities in children are successfully treated by bracing or casting and that the adult thoracic cavity develops a barrel shape with progressive emphysema. Nuss reasoned that by forcing the sternum forward with a bar, the deformed rib cartilages responsible for the development of pectus excavatum could be permanently remolded, after which the bar could be removed. Nuss developed the technique over a 10-year period, performing the operation on 42 patients between the ages of 1 and 15 years.

Follow-up evaluation was performed on 30 patients whose bar had been removed on average 2.8 years after surgery. The mean follow-up time from surgery was 4.6 years. The results of the procedure were reported as good to excellent in 26 (82%) patients. Early postoperative improvement was maintained 1 year after the bar had been removed. Five-year follow-up was available for 16 patients. All of these patients maintained the appearance achieved at 1 year after surgery. Four patients had poor or fair results, which were attributed to errors made during Nuss’s early experience with the procedure. In 3 of these patients, the bars bent because they were not sufficiently strong enough. The fourth patient had Marfan syndrome, and the sternum collapsed above and below the bar.
Operative complications in Nuss’ series of 42 patients have been minor. Small, residual pneumothoraces occurred in 3 patients, but none required a chest tube to treat. Bar displacement occurred twice in his early experience. Four patients developed skin irritation because the bar was too weak and straightened out. There was 1 wound infection, which responded to antibiotics, and the bar did not have to be removed.

Nuss’ operation offers several advantages over the modified Ravitch procedure, which involves costal cartilage removal, sternal osteotomy, and the use of stainless steel struts for temporary support in adolescent patients (2, 3). With the Nuss procedure, the operating time is reduced. Instability of the chest does not occur, and elasticity of the chest is maintained. The surgical incision across the chest is eliminated. Chest growth is not retarded, and the patient is able to resume full activity sooner. An estimated 500 Nuss procedures have been performed with no reported deaths.

The ideal age for surgical repair of pectus excavatum is before puberty. The preadolescent’s chest is compliant, and the patient’s remaining growth potential allows remolding of the costal cartilages and continued growth of the chest. The effectiveness of the Nuss procedure for teenagers and adults is uncertain, as these patients lack growth potential and their chests are less compliant. A limited number of teenagers and adults have undergone the procedure, and the early results have been good. Nuss originally reported operating on 3 patients, ages 13. The procedure has also worked well for recurrent pectus.

The most common complication for surgeons learning the technique has been displacement of the bar, which usually occurs within the first month after surgery. However, with the addition of a stabilizing cross bar, such displacement has been virtually eliminated. Overcorrection can result in the development of pectus carinatum.

**SURGICAL PROCEDURE**

Prior to surgery, a stainless steel bar (Walter Lorenz Surgical, Jacksonville, Fla.) is bent to conform to the contour of the patient’s chest at the level of the deepest part of excavatum (**Figure 1**). The bar is selected so that its length is sufficient to extend from the mid-axillary line on 1 side of the patient’s chest to the mid-axillary line on the other side.

For the operation, the patient is supine with the arms abducted. Incisions are made on the sides of the chest between the anterior and posterior axillary lines. Large subcutaneous pockets are created anteriorly and posteriorly to accommodate the bar. A Kelly or Crawford clamp is inserted through the intercostal space in line with the deepest point of the concavity and passed across the mediastinum directly behind the sternum. The electrocardiogram is monitored for arrhythmias during passage of the clamp, and passage can be monitored with a thoracoscope. The point of the clamp is pushed through the corresponding intercostal space on the opposite side of the chest (**Figure 2**). An umbilical tape is then tied to the bar, and the bar is guided across the mediastinum (**Figure 3**). The convex side of the bar faces posteriorly as it traverses the mediastinum (**Figure 4**, top). The bar is then rotated 180° with a vise grip or rotational device (Walter Lorenz Surgical, Jacksonville, Fla.) so that the convex surface elevates the sternum (**Figure 4**, bottom).

If the correction is deemed unsatisfactory, the bar is turned over, removed from the chest, and bent further so that an appropriate correction of the deformity can be achieved. In some cases, a
second bar may be necessary for satisfactory correction. The second bar is inserted 1 intercostal space above or below the first bar. A cross bar is inserted on 1 end of the bar for stabilization (Figure 5). The convex bar and the stabilizing bar are firmly sutured to the chest wall. Before the incision is closed, a positive end expiratory pressure of 5 cm of water is added to eliminate air from the chest. The surgical wounds are then closed in layers. A chest radiograph is obtained in the operating room to detect the presence of residual pneumothorax. Any residual air is aspirated. A chest tube is inserted only if there is significant pneumothorax.

**POSTOPERATIVE PROTOCOL**

Epidural anesthesia and intravenous analgesics are used for postoperative pain control. The patients are ambulated after the epidural anesthesia is discontinued. They are discharged when they are ambulatory and comfortable with oral analgesics. Prophylactic postoperative antibiotic therapy consists of cefazolin administered for the first 48 hours following surgery. The bar is completely incorporated within a month after surgery, and the patient is allowed to resume full activity at that time. The bar is removed as an outpatient procedure 2 years after insertion, when permanent remolding has occurred.

**INDICATIONS FOR SURGICAL REPAIR**

The indications for repair of pectus excavatum are not altered because of the development of the Nuss procedure. For a time, the role of surgery in the management of pectus excavatum was controversial, because improvement in cardiopulmonary function could not be conclusively demonstrated (4). Many physicians regarded the surgery as cosmetic rather than functional. However, there are documented cardiopulmonary abnormalities associated with pectus excavatum and demonstrated benefits of repair with the deformity (5). Because of the confusion regarding the physiologic effects of pectus excavatum, the current knowledge of cardiopulmonary function in patients with pectus excavatum and the potential benefits of the Nuss repair are reviewed.

The need for surgery is based on the severity of the deformity and, if necessary, an evaluation of the patient’s cardiac and pulmonary functions. Most patients with pectus excavatum are asymptomatic in early childhood. Deformities often are mild in children <6 years but become more severe with growth. Cardiac function at rest may not be altered, but with exercise, cardiac output is restricted due to sternal compression and displacement of the heart. Worsening of the deformity and development of associated symptoms occur commonly in adolescence. Symptoms include decreased exercise tolerance, weakness, fatigue, dyspnea, and tachycardia. Reactive airway disease is common in children with pectus excavatum.

Young children with minimal deformities and no symptoms can be managed with regular follow-ups. If there is deep concavity, a chest dimension index will quantitatively determine the severity of the deformity. The evaluation is performed by obtaining a chest computed tomography scan through the depth of the deformity. Measurements are made between the sternum and the vertebral column and transversely across the chest. The pectus index is determined by dividing the transverse dimension of the chest by the sterno-vertebral dimension. Normally, the transverse dimension exceeds the sterno-vertebral dimension by 2.56 times. The pectus index was first used at the Johns Hopkins Hospital. Only patients with an index >3.25 underwent surgery (6). Since then, a pectus index >3.25 has become the standard indication for surgery.
Echocardiography is beneficial in detecting cardiac compression and its consequences. There may be indentation of the right ventricle and mitral valve prolapse. Compression of the heart is greater in the upright position than in the supine position. Compression of the heart by the depressed sternum reduces stroke volume and cardiac output. Stroke volume decreases by 40% in the upright position in some patients with pectus, compared with no change in normal controls (7). With exercise, stroke volume increases less than in normal controls and remains fixed with increased work load, requiring an increase in heart rate to meet blood flow demands. Morphologic changes in the heart have also been demonstrated in patients with pectus excavatum. The right ventricular outflow tract is narrower, and end-diastolic and end-systolic areas are larger than normal controls. Right ventricular emptying is reduced compared with normal controls (8). After pectus repair, the cardiac index in the upright position has been reported to increase by up to 38% (7–9). In addition, the patient’s exercise tolerance improves, and the mitral valve prolapse disappears.

In cases of mild pectus deformity, pulmonary function is normal; however, a decrease in pulmonary function occurs in moderate-to-severe pectus excavatum. Pulmonary function studies demonstrate obstructive and restrictive defects (10). In preoperative and postoperative xenon perfusion and ventilation scintigraphy studies of patients with moderately severe pectus deformities, two thirds of the patients had abnormal ventilation before surgery, and >50% showed improvement after surgery (11). Compression of the left lung by the displaced heart was consistently observed in patients with moderate-to-severe pectus deformities. Abnormal radionuclide retention was greater in the left lung than the right lung. The standard operation in which cartilage was removed improved severe, restrictive pulmonary function; however, there was only slight or no improvement in pulmonary function in cases of moderate pectus excavatum (12, 13). Patients with a mild decrease in pulmonary function (i.e., >75% of normal) have been reported to have reduced pulmonary function after costochondrectomy (14). The loss of chest elasticity because of costal cartilage removal was detrimental to pulmonary function except in patients with severe pulmonary dysfunction (7, 12–14).

CONCLUSION

The standard costochondrectomy and sternal osteotomy described by Ravitch in 1949 provide effective anatomic correction of pectus excavatum (2). Satisfactory subjective results are achieved in 85% to 95% of patients who have the operation. Cardiac compression is relieved by the Ravitch procedure, but improvement in pulmonary function is unlikely in children with moderate deformities. This is due to the previously unappreciated decrease in chest elasticity and chest wall growth when the cartilages are removed (15, 16). When cartilage removal is too extensive or is performed too early in childhood, the results may be thoracic dystrophy and cor pulmonale (17, 18).

Currently, the ease of the Nuss technique makes it the procedure of choice for surgical repair of pectus excavatum. However, its long-term benefits may be greater. Because costal cartilages are not removed, the Nuss procedure has the potential to improve not only cardiac function, but pulmonary function as well by maintaining chest elasticity and chest wall growth. Noninvasive preoperative and postoperative studies correlating the severity of the pectus defect with cardiac and pulmonary functions will help further define the full value of this major innovation in the treatment of pectus excavatum.
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References


