SPECIAL CONTRIBUTION

Recent Experiences with Minimally Invasive Pectus Excavatum Repair "Nuss Procedure"

Objective: **To review the new technical modifications and results of 668 patients who have had pectus excavatum repair utilizing the minimally invasive technique.** *Methods:* **A retrospective chart review was conducted of 668 patients undergoing minimally invasive pectus repair from 1987 through July 2004. Since 1997, a standardized treatment pathway was implemented. Preoperative evaluation included computed tomography (CT) scan, pulmonary function tests, and cardiac evaluations with electrocardiogram and echocardiogram. Indications for operation included at least 2 of the following: progression of the deformity, Haller CT index greater than 3.25, mitral valve prolapse, cardiac compression or displacement, pulmonary function studies that indicate restrictive or obstructive airway disease, previous failed open or minimally invasive pectus repair. Technical and design modifications since 1998 have included routine thoracoscopy, the use of an introducer/dissector for creating the substernal tunnel, elevating the sternum, and routine use of a wired lateral stabilizer and polydioxanone suture (PDS) sutures around the bar and underlying rib to prevent bar displacement. The bar is removed as an outpatient procedure in 2 to 4 years.** *Results:* **In 668 patients undergoing minimally invasive pectus repairs, single bars were used in 78.1% and double in 21.7%. Lateral stabilizers were applied in 99.8% and were wired for further stability in 71%. Bar shifts before the use of stabilizers were 14.3%, which decreased to 4.6% after stabilizers were placed and 0.8% with a wired stabilizer and PDS sutures. Results were excellent in 78.5%, good in 13.1%, fair in 4.7% and failed in 3.7% after more than 1 year post bar removal.** *Conclusion:* **The minimally invasive technique has evolved into an effective method of pectus excavatum repair. Modifications of the technique have reduced complications. Long-term results continue to be excellent.**
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Key words: pectus excavatum, minimally invasive, Nuss procedure

The minimally invasive pectus repair requires no cartilage resection and no sternal osteotomy. A substernal tunnel is created with a specially designed introducer (Fig. 1). Once the introducer is in position it is used to correct the pectus excavatum by lifting the sternum out of its depressed position (Fig. 2). A curved steel bar is then placed under the sternum to maintain the correction. To prevent bar displacement a rectangular stabilizer is wired to the bar on the left and sutures are placed around the bar and underlying ribs on the right (Fig. 3).

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Subjects and Methods

Evaluation and indications for surgery. Patients are selected for surgery based on the following criteria: 1) progression of the deformity with associated symptoms; 2) a Haller computed tomography (CT) index greater than 3.25 showing cardiac compression or displacement; 3) pulmonary function studies (PFT's) that indicated restrictive or obstructive airway disease; 4) a cardiology evaluation documenting murmurs, mitral valve prolapse, abnormal rhythm, cardiac compression or displacement; 5) previous failed open or minimally invasive pectus repair.

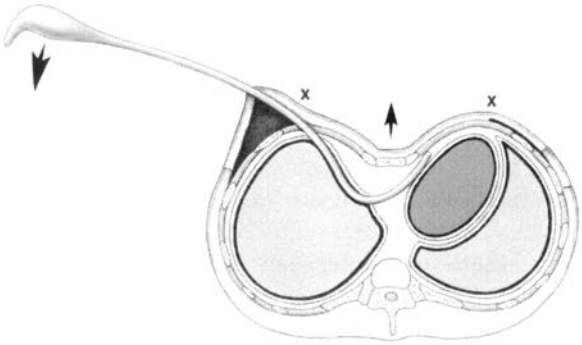

Fig. 1.

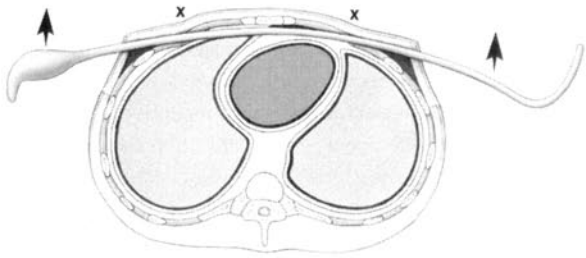

Fig. 2.

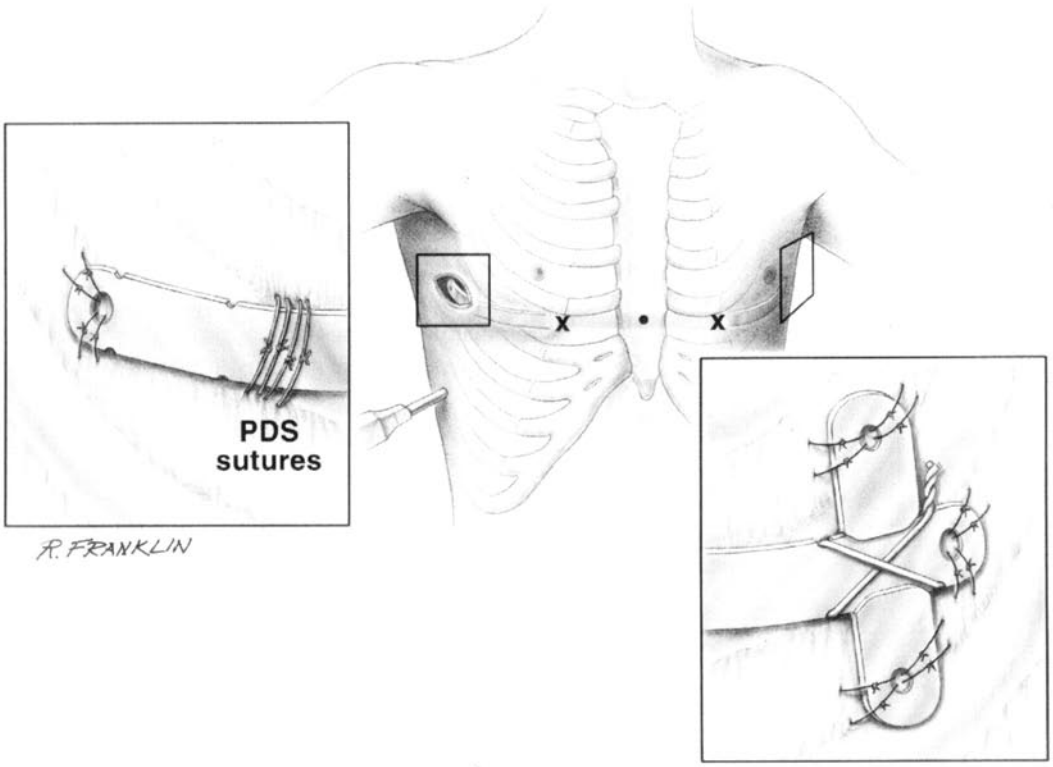

Fig. 3.

Surgical technique. Before surgery the patient is measured from mid-axillary line to mid-axillary line. A pectus bar is selected that is 2 cm shorter than this measurement because the internal chest diameter is shorter than the external diameter. The bar is bent into the desired configuration. The minimally invasive pectus repair involves making incisions on each side of the chest and creating a skin tunnel from the lateral thoracic incision to the top of the pectus ridge on each side. At the top of the ridge, bilateral thoracostomy incisions are made and then a large introducer is inserted into the chest under thoracoscopic guidance. Very carefully with the thoracoscope in place and under good vision the pleura and pericardium are dissected off the under surface of the sternum. The introducer is slowly advanced across the mediastinum and then brought out through the thoracostomy incision on the contralateral side. When the introducer is in place it is lifted on each side numerous

times, thereby elevating the sternum and correcting the pectus excavatum. Once the sternal depression has been corrected, an umbilical tape is attached to the introducer and the introducer is slowly withdrawn from the chest. The pectus support bar is then attached to the umbilical tape and under thoracoscopic control is slowly guided through the sub-sternal tunnel with its convexity facing posteriorly until it emerges on the contralateral side. Once the bar is in position inside the chest, it is turned over using the especially designed bar flippers. This gives instant correction of the pectus excavatum. Two bars are usually necessary in older patients. The bar is stabilized by wiring a stabilizer to the left end of the bar and by placing sutures around the bar and underlying ribs on the right side. These sutures are placed with a laparoscopic "endo-close" suture needle using the thoracoscope for visibility (Fig. 3). It is essential that the bar be adequately stabilized or it will become displaced. Once the bar has been stabilized the incisions are closed. The thoracoscope is removed and the pneumothorax evacuated by using a "water seal" system. The patient is kept on thoracic epidural analgesia for three or four days postoperatively and is then discharged from the hospital on the fourth or fifth day. Patients need to refrain from sporting activities for the first six weeks after surgery. However, after six weeks all patients are started on an exercise and posture program and are encouraged to participate in aerobic sports in order to facilitate chest expansion and to maintain a good posture.

Complications (Table I)

Early complications. Thoracoscopy is essential to prevent cardiac or pulmonary injury. In the 732 primary and secondary cases performed at our institution, there have been no cardiac or pulmonary injuries.

A residual pneumothorax is common after the use of thoracoscopy, however only 2.5% of patients required a chest tube. A "water seal" system combined with positive pressure respiration at the end of the procedure minimizes the incidence of pneumothorax.

Hemothorax from a bleeding intercostals vessel occurred in one patient. The patient did not require a transfusion. Thoracoscopy markedly reduces the risk of hemorrhage.

A small pleural effusion on routine postoperative X-rays is frequently present and usually resolves spontaneously in 3 to 4 days. A significant pleural effusion requiring chest tube drainage occurred in 4 (0.6%) of the patients.

Pericarditis occurred in 6 (0.9%) patients. It is thought to be due to pericardial injury and is a variant of the post-cardiomyotomy syndrome. Patients manifest with a fever, central chest pain, and a friction rub. An echocardiogram demonstrating fluid in the pericardial sac confirms the diagnosis. Patients respond well to indomethacin in most instances.

Wound infection occurred in 8 (1.1%) patients. We emphasize prophylactic measures usually taken for patients undergoing implantation of foreign materials.

Table I. *Complications*

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Deaths	0	0%
Cardiac perforations	0	0%
Pneumothorax with spontaneous resolution	349	52.2%
Pneumothorax requiring aspiration	3	0.5%
Pneumothorax requiring chest tube	17	2.5%
Pleural effusion requiring chest tube	4	0.6%
Pericarditis	6	0.9%
Wound infection	8	1.1%
Pneumonia	7	1.0%
Bar shifts requiring revision	50/668	7.5%
Shifts prior to stabilizer	16/112	14.3%
Shifts after wired stabilizer	22/473	4.6%
Shifts after stabilizer plus PDS sutures	1/129	0.8%
Overcorrection	28/668	4.2%
Recurrence following bar removal	6/383	1.5%

Patients are given intravenous antibiotic (cefazolin) immediately after induction of anesthesia. The antibiotic is continued until the patient is discharged from the hospital on day 4 or 5. If the bar becomes infected cultures are taken and the patient placed on long-term trimethoprim/sulfamethoxazole (Bactrim).

Vigorous incentive spirometry is encouraged to prevent pneumonia, which could result in a bar infection. Pneumonia occurred in 7 (1.0%) of the patients and responded well to antibiotics and incentive spirometry.

Transient Horner's syndrome secondary to the epidural analgesia was documented in 162 (24.2%) patients. It cleared in all cases when the epidural flow rate was reduced or when the catheter was removed.

Late complications. Bar displacement has remained the biggest challenge. A total of 71 (11%) patients had bar displacement, of whom 50 (7.5%) required repositioning. Prior to the use of stabilizers, the bar displacement rate was 16 out of 112 (14.3%) patients. Since the use of wired stabilizers, the incidence of bar displacement has decreased to 4.6% and with the addition of PDS sutures around the rib and bar, the incidence of bar displacement has dropped to 0.8%.

Allergy to one of the metallic components of the stainless steel bar occurred in 5 patients. It manifested as redness and pain in the area overlying the bar.

Overcorrection occurred in 28 patients, of whom 4 developed a true carinatum. These four patients had Marfan's syndrome. They are presently still being treated conservatively to see if the protrusion will resolve once the bar is out.

Of 383 patients who have had their bars removed, only 6 have had a recurrence. We address the factors that we believe contributed to the recurrences in the next section.

Results

As of July 30, 2004, 1,317 patients were evaluated for surgery and 732 have had the minimally invasive procedure (Table II). 668 have undergone primary pectus repair and 56 re-do operations. We have removed the bars in 383 patients after completion of treatment. Three hundred and twelve patients have had their bar out for more than one year. Of these, 190 patients have returned for one or more visits, with a post-bar removal follow-up of 14 years. The long-term results in this group (one year or more after bar removal) remain excellent in 78.5%, good in 13.1%, fair in 4.7%, and failed in 3.7% (Table III).

Of the 7 patients who have had a recurrence, 6 had undergone their initial repair and had had their bars removed before puberty (Fig. 4).

Our experience indicates that the bar should remain *in-situ* for 2 to 4 years and presently we are recommending 3 years. Patients who had a recurrence had their bars removed before two years[1-3] (Fig. 4).

Two additional factors that we have identified as important to ensuring an excellent long-term outcome include a slight overcorrection at the time of the repair and regular physical activity. Following repair with the minimally invasive procedure, there is significant improvement in the PFT's after 12 months (Lawson et al., presented at American Pediatric Surgery Meeting 2004).[4] This improvement is particularly significant in patients who are compliant with the exercise program.

Many of our patients experience significant body image issues prior to surgery, causing them to withdraw from participation in sports and social activities, giving rise to depression that sometimes leads to suicidal thoughts. Preliminary results using the Pectus Excavatum Evaluation Questionnaire (PEEQ)[5] indicate that surgical repair of pectus has a positive impact on the well being of the patient. In addition, of the 359 patients who have completed our postoperative evaluation questionnaire, 90.5% report being either happy or very happy with the results of their surgery. And 86.1% have noted an increase in exercise tolerance.

Discussion

The number of bars required depends on the size of the deformity and the age of the patient. Most older patients—sixteen and older—require two bars. Two bars not only give a much better result, they also spread the pressure over a wider area making displacement less likely and decreasing the duration of the postoperative pain and recovery.

Bar fixation is essential to prevent bar displacement. The current system of wiring a stabilizer to the bar on the left side and applying several PDS sutures to the bar and underlying ribs on the right side, under thoracoscopic guidance, has worked well with only a 0.8% displacement rate.

The age of the patient at the time of surgery plays a significant role both in the speed of recovery and the long-term results (Fig. 4). Before puberty children have a soft and malleable chest and, therefore, recover from the minimally invasive procedure in one to two weeks. During the teenage years they require two or three weeks to recover and if they are over twenty they require one to two months to recover.

However, the long-term results are better in the older patients, especially if they have completed their growth at the time of bar removal. Numerous centers routinely

Table II. *Demographics*

	n	
Patients evaluated	1,317	
Primary surgeries	668	
Mean age		13.8 years (22 months–29 years)
Mean Haller CT index	626	4.7 (2.4–31)
Cardiac compression CT	560	85.8%
Mitral valve prolapse	91	14.0%
PFT as measured by FEF 25–75%	590	
<80%	292	49.5%
Previous failed Ravitch	30	4.4%
Previous failed Nuss	26	3.9%
Previous failed Leonard	2	0.3%
Single pectus bar	522	78.1%
Double pectus bar	145	21.7%
Triple pectus bar	1	0.1%
Stabilizers	666	99.8%
Wired	473	71.0%
Mean blood loss		12 ml (5–30 ml)
Average length of stay		5 days (3–11 days)

CT, Computed tomography.

Table III. *Results*

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Results after bar removal of more than 1 year	190*	
Excellent	149	78.5%
Good	25	13.1%
Fair	9	4.7%
Failed	7	3.7%

*Based on patients who have returned 1 to 15 years following bar removal.

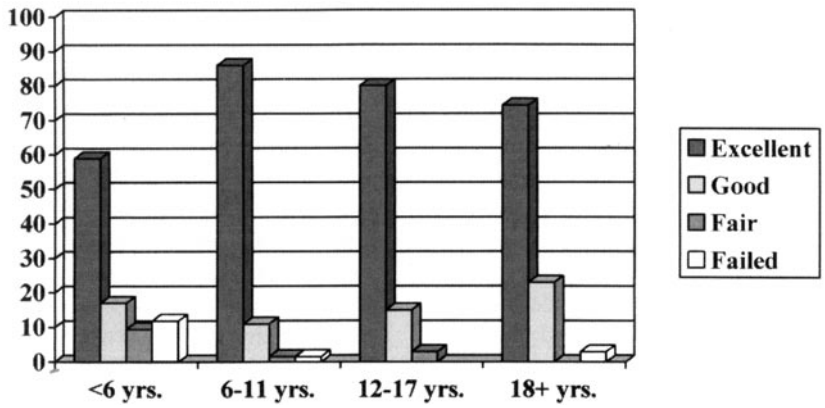


Fig. 4. Long-term results by age at time of surgery.
yrs., Years.

operate on patients in their thirties and forties with excellent results.[6-8]

Duration of bar placement is important (Fig. 5). Our experience is similar to that of the orthodontic surgeons who apply braces to the teeth for two years and then to prevent teeth from moving apart again they apply retainers for another two–three years. We have found that the bar needs to remain in place for two to four years and presently we are recommending three years. This is especially important in young children whose bar is removed before they have gone through their pubertal growth spurt. In these children we may leave the bar in for as long as four years provided they have not outgrown their bar.

Exercise is a vital component of the pectus repair. At rest the tidal volume is approximately 10% of total lung capacity. Since many patients play no sports they never stimulate their cardiopulmonary system. So even though the chest capacity is markedly increased by the repair (Fig. 6) the chest may sink back in again after bar removal if the patients do not do their deep breathing and posture exercises. We give all our patients deep breathing and posture exercises to do every morning and evening and also encourage them to participate in aerobic sports such as soccer, basketball, track, swimming, etc.

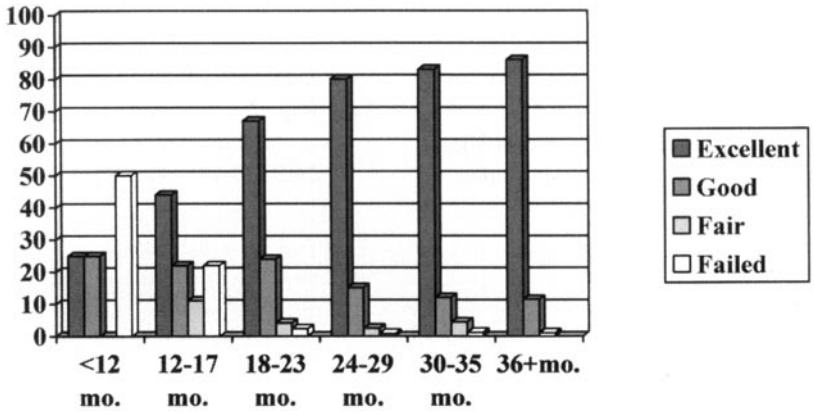
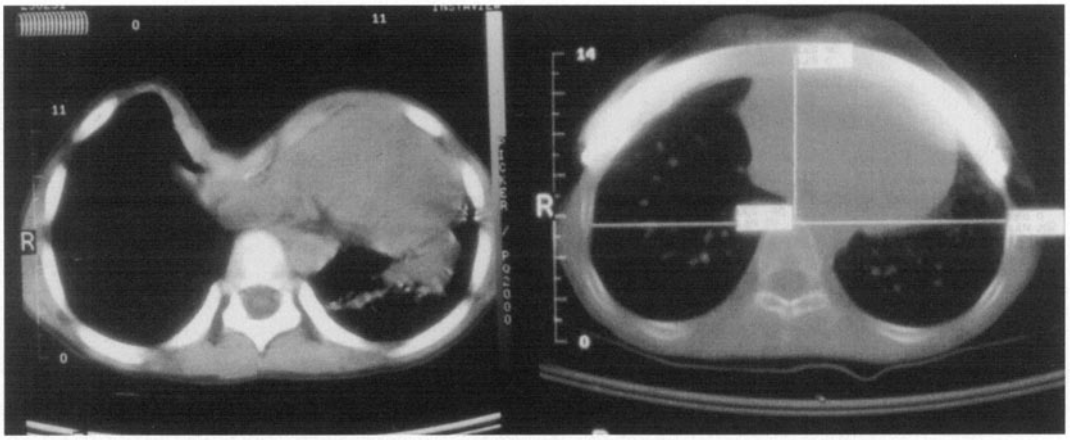


Fig. 5. Results after bar removal by time bar *in situ*. *mo.*, Months.



A B

Fig. 6.
A: Preoperative: severe pectus excavatum with cardiac compression and displacement; pulmonary atelectasis.
B: Postoperative: bar still in position.

Conclusion

Pectus excavatum can be corrected at any age using the minimally invasive Nuss technique. The best long-term results are achieved if the bar stays in place 3 years, the patients are older than 12 years at the time of bar removal, and they participate in aerobic sports. The procedure is easier to perform in young patients and they recover more quickly from the operation than older patients, but the risk of recurrence is higher if the bar is removed before puberty.

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