

Experience and Modification Update for the Minimally Invasive Nuss Technique for Pectus Excavatum Repair in 303 Patients

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Purpose: The aim of this study is to review the new technical modifications and results of 303 patients who have had pectus excavatum repair utilizing the minimally invasive technique.

Methods: A retrospective chart review was conducted of 303 patients undergoing minimally invasive pectus repair from 1987 through August 2000. Since 1997, a standardized treatment pathway was implemented, and 261 of the 303 patients have been treated on this pathway. Preoperative evaluation included computed tomography (CT) scan, pulmonary function tests (PFT), and cardiac evaluations with electrocardiogram (EKG) and echocardiogram. Indications for operation included at least 2 of the following: progression of the deformity, exercise intolerance or restrictive disease on PFT, Haller CT index greater than 3.2, mitral valve prolapse (MVP), or cardiac compression. Technical and design modifications since 1998 have included routine thoracoscopy, the use of an introducer/dissector for creating the substernal tunnel and elevating the sternum, and routine use of a wired lateral stabilizer to prevent bar displacement. The bar is removed as an outpatient procedure in 2 to 4 years.

Results: In 303 patients undergoing minimally invasive pectus repairs, single bars were used in 87% and double in 13%. Lateral stabilizers were applied in 70% of patients and were wired for further stability in 65%. Bar shifts before the use of stabilizers were 15%, which decreased to 6% after stabilizers were placed and 5% with a wired stabilizer. Excellent results were noted in 85% with failure in only 1 patient. Complications included pneumothorax with spontaneous resolution in half of the patients and pericarditis in 7.

Conclusions: 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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INDEX WORDS: Pectus excavatum, minimal access, minimally invasive surgery, computed tomography scans in chest disease, thorax abnormalities.

IN 1997 we reported our 10 years of experience with a minimally invasive technique for the repair of pectus excavatum.¹ That report encompassed our experience with 42 patients undergoing repairs with this technique. In 1998 we reported our experience with this technique in a greater number of patients, including older patients and those with deformities of increased severity.² In this report, we discuss the latest surgical and technical modifications that have been made since. We also discuss the results of 303 patients who have had primary pectus excavatum repair at a single institution utilizing the minimally invasive technique and validate our assertion of 1997 that this is an effective method of repair for pectus excavatum deformity with excellent long-term results.

MATERIALS AND METHODS

Charts of 608 patients, who were evaluated for chest wall deformities at The Children's Hospital of The King's Daughters from 1987 through August 2000, were reviewed retrospectively and entered into a database. Evaluation included collection of demographic data, subjective clinical symptoms and objective signs, categorization of the deformity, nonoperative or operative management, surgical data, complications, and classification of surgical outcome.

Evaluation and Indications for Operation

Evaluation by complete history, including interview/questionnaire regarding exercise tolerance and endurance, shortness of breath and chest pain with exertion, and frequency of upper respiratory tract infections were obtained. Complete physical examination was done for all patients and included photographs to document the deformity. Patients who did not have a deformity severe enough to require operation underwent an exercise program in an attempt to halt the progression of the deformity and were followed up at 6-month intervals. Patients who had findings of a deformity severe enough to be considered candidates for operative correction or had documented progression of their deformity underwent preoperative evaluation. In 1997, a treatment pathway was developed based on objective measures, which included thoracic computed tomography (CT) scan, pulmonary function tests, and a cardiac evaluation that included an electrocardiogram (EKG) and an echocardiogram.

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CT scan measurements utilized the Haller index for severity³ and also were utilized to assess cardiac and pulmonary compression and displacement, asymmetry of the deformity, sternal torsion, and ossification of the cartilages in patients with previous repairs. Pulmonary function tests were done in all patients old enough to cooperate with testing, and most often were done in the resting state. Cardiology evaluation included examination by a pediatric cardiologist, with EKG and echocardiogram, and included evaluation for cardiac compression, mitral valve prolapse, conduction abnormalities, or structural abnormalities.

Determination of a severe pectus excavatum and the need for repair included 2 or more of the following criteria: (1) a Haller CT index greater than 3.25; (2) pulmonary function studies that indicated components of restrictive or obstructive airway disease; (3) a cardiology evaluation in which the compression caused mitral valve prolapse, abnormal rhythm, murmurs, displacement or conduction abnormalities on the echocardiogram, or EKG tracings; (4) documentation of progression of the deformity with associated subjective symptoms other than isolated concerns of body image; (5) previous failed Ravitch procedure; or (6) failed minimally invasive procedure.

Operative and Postoperative Evaluation

Surgical measures included estimated blood loss, number of bars, use of stabilizers and wires, complications, and length of hospital stay.

Surgical Technique

Since our initial report in 1997,¹ there have been several modifications made to the technique and the design of the equipment used, including the following:

1. *Thoracoscopy.* Direct visualization of the mediastinal structures with routine thoracoscopy in all cases utilizing 3-mm or 5-mm instrumentation has made the procedure much safer. The thoracoscope is inserted through the right lateral chest wall, 2 interspaces below the right lateral thoracic incision. At the end of the procedure after fascial closure of the thoracic incisions and before removal of the thoracoscopic trocar, the CO₂ insufflation tubing is cut and placed into a bowl of normal saline, creating a water seal. The anesthesiologist applies positive pressure ventilation, and 5-mm positive end-expiratory pressure (PEEP) until the accumulated CO₂/air has been expressed as confirmed by cessation of the bubbling or by reinsertion of the thoracoscope.

2. *New Introducer.* The new introducer (Fig 1) facilitates creating the substernal tunnel, passing umbilical tapes, decreasing the size of the entry tract, and is especially important in elevating the sternum before insertion (Fig 2). Elevation of the depressed sternum before bar insertion is possible because of the strength of the new introducer. After passage of the introducer across the mediastinum, the anterior chest wall can be elevated carefully out of its concave position by lifting the introducer on each side of the chest, thereby correcting the pectus

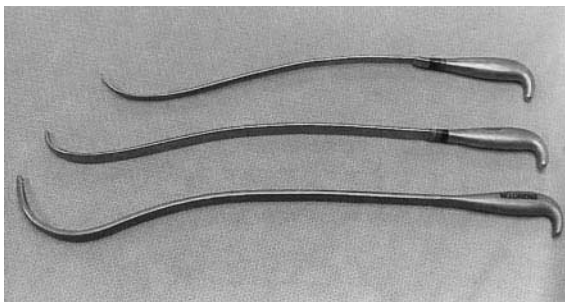


Fig 1. Introducers.

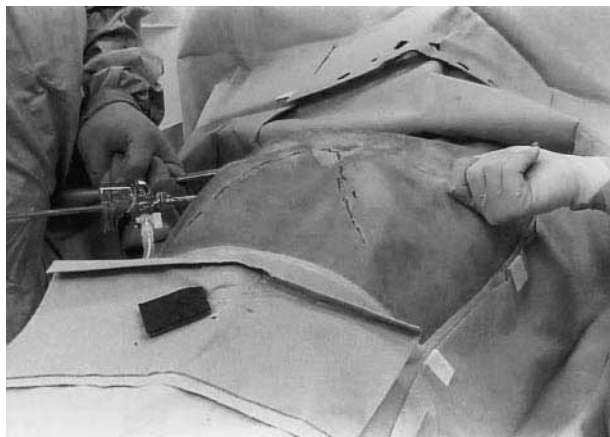


Fig 2. Elevation of sternum with introducer.

excavatum before bar insertion. This elevation of the anterior chest wall is repeated several times until the sternum has been raised to its desired position. The introducers range from small to extra large and have varying degrees of curvature to assure that the blunt tip is able to “hug” the underside of the sternum and avoid pericardial injury. The introducer also can be used to gently dissect the pericardium away from the sternum and has an eyelet for threading an umbilical tape.

3. *New bar rotational device.* Rotation or “flipper” instruments have replaced the vise grip once used to turn the bar over. These devices were designed to offer more torque with less resistance when turning the bar into position (Fig 3).

4. *New stabilizer.* A “stabilizer” device has been developed in 2 sizes to prevent bar displacement. We use number 3 surgical steel or 18-gauge Luque wire in a figure-of-eight pattern to prevent the stabilizer from sliding off the bar (Fig 4).

5. *Pectus bar modification.* The pectus bar also has undergone some minor modifications to ease placement. The ends have been rounded to ease passage through the substernal tunnel, and the ends have been “toothed” or serrated over an increased area to promote scar tissue formation and to help with wire fixation of the stabilizer (Fig 4).

6. *Analgesia.* Thoracic epidural analgesia is utilized routinely for postoperative pain management for 2 to 4 days.

7. *Postoperative activity.* Patients are transferred from the postanesthesia care unit directly to the surgical floor and usually are out of bed to a chair on the day of operation. At 2 months postoperatively, patients are permitted to return to all normal activities.

8. *Bar removal.* Bar removal 2 to 3 years after initial insertion is done as an outpatient procedure and is completed without flipping the

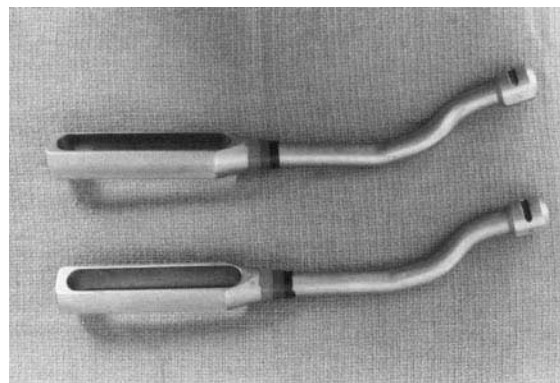


Fig 3. Bar rotational device, or “flipper.”

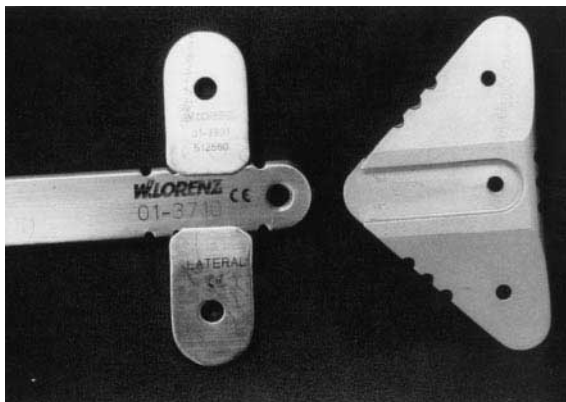


Fig 4. Stabilizer and pectus bar with rounded ends.

bar. The ends of the bar are mobilized, the stabilizers are removed, and a medium-sized bone hook is used to pull on the end of the bar while rotating the patient in the opposite direction. Alternatively, a small bar bender may be utilized to reverse-bend the externalized portion of the bar as it is removed from the chest in short segments to prevent the need for a lateral decubitus position during removal. This is necessary if 2 stabilizers are used on the bar.

Outcome Classification and Long-Term Follow-Up

Patients are followed up at 2 and 6 months postoperatively and then yearly. Long-term assessments included years postoperation; bar removal; and subjective classification of the results into excellent, good, or failed categories. An excellent repair indicates the patient experienced total repair of the pectus and resolution of associated symptoms. A good repair was distinguished by an improved but not totally normal pectus appearance but improvement of associated symptoms. A failed repair was marked by a recurrence of the pectus deformity and associated symptoms or need for additional surgery after final removal of the bar. In addition, patients with EKG conduction abnormalities or MVP had follow-up assessments, and patients old enough to have pulmonary function tests (PFT) were reassessed with repeat studies.

RESULTS

Demographics

A total of 608 patients were evaluated for chest wall deformities from 1987 through August 2000. Three hundred twenty-six were judged serious enough to undergo surgical repair, and 303 initial minimally invasive procedures were done at our facility.

Of these 303 patients, 296 (97.6%) had pectus excavatum, and 7 (2.3%) had mixed pectus excavatum and carinatum. One patient (0.3%) had associated Poland syndrome, and 1 (0.3%) had associated complex cardiac anomalies (Atrio-Ventricular [AV] canal). Marfan’s syndrome was confirmed or suspected in 65 patients (21.5%) and Ehlers-Danlos syndrome was noted in 6 patients (2.0%). The male to female ratio in patients undergoing repair was 4:1 with 243 boys and 60 girls. The median age was 12.4 years, with a range from 21 months to 29 years. Preoperative evaluation included CT scan in 268 patients with an average Haller CT index of 5 (range, 2

Table 1. Demographic Data of 303 Patients With the Minimally Invasive Repair

Mean age at operation (range)	12.4 yr (21 mo-29 yr)
Gender (M:F)	243:60
Haller CT index	268 (median, 5; range, 2-21)
Cardiac compression on CT or echocardiogram (%)	248/277 (89.5)
Mitral valve prolapse (%)	48/230 (20.8)
Pulmonary Function tests	247
Mild restrictive (FEV ₁ 80%–90% predicted)	65/247 (26.3%)
Moderate restrictive (FEV ₁ 60%–80% predicted)	72/247 (29.1%)
Severe restrictive (FEV ₁ <60% predicted)	14/247 (5.7%)
Results within normal	97/247 (39.2%)

to 21). Cardiac compression was noted on echocardiography or CT scan in 248 of 277 (89.5%) patients, and mitral valve prolapse was noted in 48 (15.8%) patients. PFT was completed in 247 patients and demonstrated abnormalities in 151 (61%) patients (Table 1).

Operative Procedure, Analgesia, and Length of Stay

In 265 (87.5%) patients, a single bar was inserted. Two bars were inserted in 38 (12.5%) patients. Lateral stabilizers were placed in 211 (69.4%) patients, and were wired in 138 of 211 (65.4%). Blood loss in most patients was minimal, with the exception of one patient in whom a hemothorax developed. Epidural analgesia was used for 2 to 4 days. The median length of stay (LOS) was 5 days, with a range of 3 to 10 days.

Early Complications

Table 2 summarizes complications that occurred during the initial hospital stay. There were no deaths nor

Table 2. Early Complications

Deaths	0
Cardiac perforation	0
Pneumothorax requiring percutaneous aspiration	3/303 (1.0%)
Pneumothorax requiring chest tube	5/303 (1.6%)
Pericarditis	7/303 (2.3%)
Pericarditis requiring drainage	1/303 (0.3%)
Medication reactions	11/303 (3.6%)
Pneumonia	2/303 (0.7%)
Hemothorax	1 (0.3%)
Nosocomial infection	2 (0.7%)
Transient Horner’s syndrome	116/155* (74.8%)
Transient extremity paralysis	1 (0.3%)
Superficial wound infection	7/303 (2.3%)
Bar infection	2/303 (0.7%)
Incidental findings on x-ray (spontaneous resolution)	
Residual Pneumothorax	155/261 (59.6%)
Pleural effusion	148/261 (56.7%)

*One hundred fifty-five patients examined for Horner’s during initial introduction of epidural.

Table 3. Late Complications

Bar shifts requiring revision	26/303 (8.6%)
Before stabilizer	14/92 (15.0%)
After stabilizer	12/211 (5.6%)
With wired stabilizer	7/138 (5.0%)
Hemothorax requiring treatment	2/303 (0.7%)
Wound infection	7/303 (2.3%)
	11/303 (3.6%)
Over correction or carinatum deformity	4/303 (1.3%)
Bar allergy	3 (1.0%)
Skin erosion	1 (0.3%)
Thoracic chondrodystrophy	0

were there any cardiac perforations during the 303 repairs. Pneumothorax requiring percutaneous aspiration has occurred in 3 (1.0%) repairs and requiring chest tube drainage in 5 (1.6%) repairs. Hemothorax requiring drainage occurred after 1 (0.3%) repair. Three (1.0%) pleural effusions required treatment by chest tube or aspiration.

Pericarditis requiring treatment occurred after 7 (2.3%) repairs, 1 requiring pericardiocentesis. Pneumonia occurred after 2 (0.7%) repairs, and medication reactions have occurred after 11 (3.6%) repairs. Wound infection occurred after 7 (2.3%) repairs, resulting in bar infection and eventual bar removal in 2 (0.7%) patients.

Late Complications

Bar displacement requiring repositioning occurred in 26 of 303 (8.6%) patients. Of these 26 displacements, 14 of 92 (15.2%) occurred without stabilizers and 12 of 211 (5.7%) occurred with a stabilizer without wiring. With the addition of wiring of the stabilizer 7 of 138 (5.0%) displacements occurred (Table 3).

Late hemothorax in 2 patients developed with one occurring secondary to trauma. Both of these patients underwent thoracoscopy with drainage of the hemothorax. No active bleeding was found with a presumed etiology therefore being an injury to an intercostal vessel.

Three (1.0%) patients had unsuspected allergies to the metal in the bars or stabilizers. These presented as rashes in the area of the bar or stabilizer, and required revision to custom-made bars of other alloys (Table 3).

Eleven (3.6%) patients had a mild overcorrection of their deformity, and a true carinatum deformity developed in 4 patients (1.3%). Of the patients in whom a true carinatum deformity developed, 3 (75%) had Marfan's syndrome, and the other had Ehlers-Danlos syndrome. No patient has had thoracic chondrodystrophy.

One patient (0.3%) had erosion of the bar through the skin. This occurred in a patient with both Marfan's syndrome and an older-style bar with squared ends.

Early and Long-Term Chest Wall Appearance and Functional Results

The initial cosmetic and functional results are excellent in 257 (84.5%) patients, good in 45 (14.8%) patients, and failed in 1 (0.3%) patient overall. The bars have been removed in 71 (23.4%) patients, with 23 (32.3%) patients more than 5 years post-bar removal, 16 (22.5%) patients 1 to 5 years post-bar removal, and 32 (45.1%) patients less than 1 year post-bar removal. In these patients, cosmetic and functional results are excellent in 51 (71.8%), good in 14 (19.7%), and have failed in 6 (8.5%). As seen in Table 4 there is a good correlation between initial and long-term results (Spearman's $\rho = 0.60$; $P < .001$).

Among 65 patients with confirmed ($n = 16$) or suspected ($n = 49$) Marfan's syndrome, bars have been removed in 13 (20%). Among these patients, long-term results are excellent in 8 (61.5%), good in 2 (15.4%), and failed in 3 (23.1%).

Cardiac compression has been relieved in all patients with the exception of the 6 patients with failure of the procedure 6 of 303 (1.9%). Of the 141 patients with conduction abnormalities, 117 of 141 (83%) have documented resolution of these preoperative findings. In the 48 patients with MVP, 20 have had postoperative evaluation, and 9 of 20 (45%) have documented resolution of MVP by echocardiography.

Early evaluation of PFTs postoperatively before bar removal shows improvement or no change in 117 of 163 (72%) patients.

DISCUSSION

In 1997¹ we reported the 10-year experience of a minimally invasive technique for pectus excavatum repair followed by a second report involving 117 patients and published in 1998 confirming the ability of the chest wall to remodel by internal bracing without subperichondrial cartilage resection or sternal osteotomy.²

Criteria for repair often have been empiric, and doc-

Table 4. Long-Term Results in 71 Post-Bar Removal Patients

Initial Result	End Result*		
	Excellent 51 (71.8%)	Good 14 (19.7%)	Failed 6 (8.5%)
Excellent 56 (78.9%)	48 (67.6%)†	8 (11.3%)	0
Good 14 (19.7%)	3 (4.2%)	6 (8.5%)	5 (7.1%)
Failed 1 (1.4%)	0	0	1 (1.4%)

*Twenty-three (32.3%) patients are more than 5 years post-bar removal, 16 (22.5%) are between 1 and 5 years post-bar removal, and 32 (45.1%) are less than 1 year post-bar removal.

†Spearman's $\rho = 0.60$, $P < .001$ indicates that initial results are significantly correlated with long-term results.

umentation of results in most series is subjective.⁴⁻¹³ Since 1994 we have used CT scans as one of 5 objective indications for operation. Using the Haller index³ as one criterion shows the severity of the deformities that can be repaired successfully by this technique. Our current median Haller index of 5 shows an increase since our initial report, and documents our evolution of applying the minimally invasive technique to more severe deformities. In 6 patients (2.0%), the CT index was noted to be less than 3.25 because they had eccentric or barrel chest deformities, which falsely decreases the CT index.

Cardiac evaluations have been a routine part of our criteria for operation and have shown cardiac compression on CT scan or echocardiography in 89.5% of the patients so evaluated. This resolved after repair in all patients. Mitral valve prolapse was noted in 20.8% of our patients, which is a lower frequency than others have reported,^{14,15} but is higher in frequency than the general population.¹⁶ Early postoperative evaluation has shown resolution of MVP in 45% of these patients suggesting cardiac compression an etiology for MVP in patients with PE.

Pulmonary function studies supported the need for operation, with 61% of the patients in the low-normal to restrictive disease range. Primary care physicians had treated 17% of their patients for asthma, which is a higher percentage than in other reports.⁵ Many of these patients have improved symptomatically, and have discontinued preoperative asthma medications since surgery. Our early results with the bar still in place show improvement or no change in 72% of patients and a decrease in 28%. The bar itself may produce some restriction as the patient grows, and, therefore, studies after bar removal will be required to verify our initial impressions.

We recommend an exercise and posture program for patients with mild deformities, and the median age for operation has increased from 5 to 12.4 years since our initial report. This is in part because of pediatricians who have started referring older patients whom they had previously advised not to have surgery (Fig 5). The range

in age is from 13 months to 29 years. The 2 patients who were operated on in infancy had severe pectus deformities combined with other major congenital anomalies. We do not routinely recommend infant repairs and currently feel that the optimum time to repair the deformity is between 6 and 12 years of age. This recommendation considers the developmental cooperation of patients at this age, along with the flexibility of their chest walls. Although this technique appears to be as successful in older patients, recovery time is longer, and they frequently require 2 bars for complete correction and are more prone to bar displacement.

Modifications of the technical aspects of the procedure have improved the safety and results of this operative approach. Although we had, on occasion, utilized thoracoscopy for this technique, the routine use of thoracoscopy began in 1998 after a single case of cardiac perforation that we reported in a subsequent publication of technique.² This occurred during a visiting professorship at another institution. The patient survived this complication and it has not been repeated since the addition of routine thoracoscopy. The thoracoscope is inserted preferentially from the right side, because the heart in severe pectus deformities often is displaced into the left thorax and obscures the view. In all but a few cases, the entire field of dissection can be visualized from the right, and, in cases in which the depression prevents visualization to the left side, left thoracoscopy or bilateral thoracoscopy has been used.

Residual pneumothorax was commonplace on postoperative x-ray (59.6%). In 155 of 163 (95%) patients, it resolved spontaneously. In another 3 (1.0%) patients, percutaneous needle aspiration was performed, and 5 (1.6%) patients required chest tubes. Use of an introducer that makes a smaller opening into the chest in contrast to a large Kelly or Crawford clamp, as well as the use of the thoracoscopic trocar tubing as a means of evacuating residual gas under water seal before removal, has minimized this problem.

The use of epidural analgesia has been a great adjunct to this procedure, which although minimally invasive, is still painful. Continuous epidural analgesia followed by a transition to oral narcotic, NSAIDs, or COX2 inhibitors has allowed early mobilization and improved pulmonary toilet postoperatively. We have noted the frequent occurrence of transient Horner's syndrome in patients with thoracic epidural analgesia catheters in 116 of 155 patients examined (74.8%), and, although the etiology is unclear, this side effect has been reported previously.¹⁷⁻²⁴ The Horner's has resolved in all cases but one by decreasing the infusion rate or discontinuing the epidural. In one patient with a pectus index of 10.0 and severe Raynaud's phenomenon, preoperatively the Horner's syndrome took 3 months to resolve.

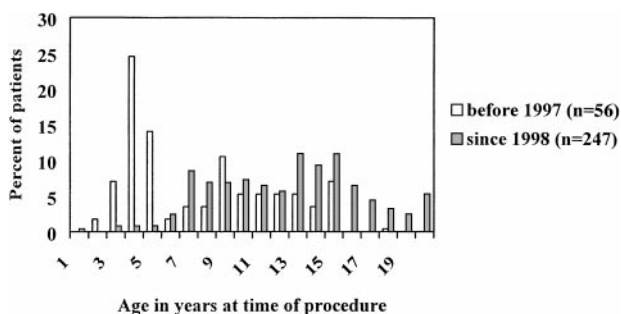


Fig 5. Age distribution by time of procedure.

Pericarditis has occurred in 7 (2.3%) patients, and was not observed in our initial 42 patients.¹ The presence of a friction rub alone, which occurs commonly when a small amount of residual CO₂ remains in the mediastinum, should not be confused with this problem. The presence of persistent fever and chest pain in addition to a pericardial friction rub, were the initial signs of this problem, which was confirmed by echocardiography. Of these 7 patients, one had a small perforation in the pericardium during insertion of a Crawford clamp. One patient (.03%) required a pericardial drainage catheter. All of the other patients with pericarditis have resolved with a short course (10 to 14 days) of NSAIDs (Indomethacin, n = 5), or baby aspirin (n = 2). Postcardiotomy syndrome occurs after both cardiac surgery and trauma. The etiology is unknown, but immune and viral infectious mechanisms have been suggested.²¹⁻²³ We have not seen this complication since we began using the new introducer, which allows gentle dissection of the pericardium away from the underside of the sternum and theoretically reduces the possibility of a traumatic cause for pericarditis.

Bar displacement was noted with increasing frequency as we began to apply this technique to older patients with more severe and asymmetric deformities. We had been working on the development of a stabilizer when we first reported our series in 1997, and in late 1998, we began to routinely utilize stabilizers in all but the youngest patients. After presentation of a review of this technique in 1999 in which we noted a decrease in bar displacement, we recommended that stabilizers be used in most patients.²⁴ It also was noted that the stabilizer could slide off the bar unless the two were wired together. The addition of wiring the stabilizer to the bar has reduced the incidence of bar migration to 5%, even in patients participating in multiple sporting activities. We continue to stress that proper placement of the bar and the decision for multiple bars is extremely important and obviously has a learning curve, as suggested by the results of others who have begun to apply our technique.²⁴⁻²⁶ We have not

had to remove a bar for pain, but have revised several bars that were inserted elsewhere. When the bar is not positioned well, the intercostal muscles may be stripped from the rib, causing increased pain, with recurrence of the deformity and potential flipping of the bar.

Late failure of the procedure has occurred in 6 (8.5%) of the 71 patients whose bars have been removed. Two failures early in our experience occurred when the bar was made of titanium and was not strong enough to support the pressures exerted by the chest wall deformity. Three of 4 later failures have been in patients with Marfan's syndrome and in 1 patient who had a bar infection that required removal after only 1 year. In addition, the majority of overcorrections occurred in patients with Marfan's syndrome. In our initial report, we mentioned that one patient had his bar removed 7 months postsurgery because of overcorrection (carinatum defect). He was 8 years old at the time and suffers from Marfan's syndrome. Subsequently, a recurrence of his excavatum developed. We, therefore, recommended leaving the bar in for at least 2 years and 3 years for patients with Marfan's syndrome. Patients with mild overcorrection or carinatum deformity have either had symptoms resolve after removal of the bar at 2 years or have had orthotic treatment with success.²⁷ We have not had an occurrence of thoracic chondrodystrophy that can occur after too early or too extensive pectus repair.²⁸

Bar removal was completed in 71 (23.4%) patients, with a mean time for removal of 2.3 years (range, 4 months to 4 years). Twenty-three patients are more than 5 years post-bar removal and continue to have excellent results. In addition, because of the correlation between initial and long-term results we can expect excellent outcomes for the majority of the 233 patients who will have their bars removed in the near future. The combination of excellent long-term results and a low complication rate indicates that the minimally invasive technique for repair of pectus excavatum has evolved into an effective procedure for the full spectrum of this deformity.

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Discussion

E. Fonkalsrud (Santa Monica, CA): I would like to congratulate Dr Nuss on this excellent report with superb results with a large number of patients and an increasing age group compared with the report 4 years ago. I would particularly like to express our appreciation for stimulating the interest in pediatricians as well as parents in getting interest in having these very common deformities come for repair, which was not the case before your report 4 years ago.

I have a few questions. What is the effect of the rigid curved bar, which you placed in your initial group of patients (average age about $4\frac{1}{2}$ years), on the growth of the chest wall in these rapidly growing children? If you put an appropriate-size bar in a 2 year old and he doubles his size in the next few years, does that cause any constriction of the chest?

You mentioned that all patients receive epidurals for 2 to 4 days. Could you tell us more about the pain management during the weeks after repair? How long are intravenous analgesics used, because it is a very painful operation? We recently had occasion to attach a spring scale on the sternum of a 19-year-old patient when we did an open repair to elevate the sternum to the desired level. It took over 40 pounds of pressure to lift that sternum to a near-normal level, so your operation must put quite a bit of pressure on the support bars.

Have you followed up with any of your patients who had the bars placed at an early age into adolescence,

when there is very rapid skeletal growth, to see if there is recurrence at that time?

D. Nuss (response): What is the effect of the bar on young children? The bar does not affect the growth of the chest if it is removed within 3 years. A few patients have even tolerated the bar for 4 years. What we found in younger children was that if there was a recurrence during the time that the bar was in place, the recurrence would slowly get worse as the child continued to grow. If the patients had an excellent result at the time of bar removal, they have maintained that excellent result. Since we started this procedure in 1987, we do, in fact, have numerous patients who have gone through their pubertal growth spurt and have maintained their excellent result. Their chest has grown normally.

As far as the pain is concerned, they do have considerable pain, and it depends on their age. The younger patients usually do not need any pain medication after 5 days. Older patients have pain for a month or 2.

M. Nahmad (Miami, FL): As you know, we have been using your technique for quite a while. All of these patients have some kind of asymmetry of the pectus deformity. Regardless of the amount of asymmetry, do you still put the bars in?

D. Nuss (response): Yes. We use the bar for all our patients. We warn those patients who have asymmetry that they may still have some asymmetry after the pro-

cedure. In other words, we will tell them that we may be able to do an 85% or 90% correction.

A. Coran (Ann Arbor, MI): Don, I think I can speak for the organization in saying that APSA and the pediatric surgical community are very grateful to you for all the work you have done in introducing this new technique, as it has changed the whole management of chest wall deformities. A lot of us have subscribed to it and are doing it, but I do think there are some problems, one of which we found. Even with stabilizer use, the bars still flip as you had shown in one of your last slides. One of the things we have done in the last 15 of these is to not use the stabilizer but rather use number 5 surgical wire and use the thoracoscope to watch the wire and in bring it directly around the bar and the rib. With those, there has been no slippage at all. That is a little extra technical thing that I think does help.

The other thing is that we have not had a chance to remove very many bars because we have only been doing this for a little over 2 years, but, in the few I have had to take out, it has been some grunt to remove that. The thing is so stuck that you need a Paul Bunyan on either side of the bar to flip it enough to slide it out. What tricks do you have for doing that?

And then my final question relates a little bit to Michel Nahmad's, and that is, on the asymmetrical, but even more so on the Poland's syndrome, are you finding that you are getting a cosmetically satisfactory repair?

D. Nuss (response): Just to answer the last question first, we do not advocate this procedure for Poland's syndrome. In Poland's syndrome there is an absence of ribs and muscles that this will not correct. If you think that putting a bar in will facilitate whatever else you are doing for the Poland's syndrome, by all means insert a bar, but it is not an ideal procedure for Poland's.

As far as bar removal is concerned, it is very variable on how easy it is to get out. In the younger children, we usually do not have any problem at all. The trick is to mobilize one side. If you have a stabilizer on one side, then mobilize that side. If you have a stabilizer on both sides, you have to mobilize both sides. Then we insert an orthopedic hook into the hole at the end of the bar, and rotate the patient over in the opposite direction to the one we are pulling in. So, if we are pulling the bar to the left, then we turn the patient to the right. In other words, he goes into a right decubitus position, and one can then just simply slide the bar out. We have not had any problem using that maneuver. If you have a very big patient, one who is difficult to turn, you can use the small bar bender to turn the bar in the opposite direction, so you pull out a little bit of the bar, bend it in the opposite direction and then pull it out a little bit more. The easiest is to turn the patient and just slide the bar out.

We do not consider ourselves to have a monopoly on

the modifications. I think it is only natural that surgeons will find ways of doing things better and come up with suggestions. If you find that the wire works well for you, then I think that is fine. I would be a little bit concerned about putting a wire around the rib in terms of (a) injury to the intercostal nerve and (b) injury to the rib, creating calcification of the tissues, which may explain why you have had such difficulty with bar removal.

G. Holcomb (Kansas City, MO): We are beginning to see more patients in the 20-year-old age group and older who want their pectus excavatum corrected. I noticed in your slide your oldest patient is 29 years old. Do you have any thoughts about the 20- to 30-year-old patient? Are there any tips you can give us for correcting those patients?

D. Nuss (response): I do not have any brilliant tips. I will tell you this; these patients usually are extremely grateful, more so even than the younger patients. There are members in the audience who have more experience with the older patients than we do. I know Dr Colombani told me he had operated on a 40-year-old patient the other day. Dr Coln in Dallas is presenting a paper at the international surgery meeting on his experience in patients over 30, and he said he has had very good results. The main thing is to warn them that they will have pain, and the pain will last for more than a week or 2, it may last up to 2 months.

C. Priebe (Stony Brook, NY): This was an excellent presentation. With your present experience with your procedure, what do you think is the ideal age to suggest it be done? When you see the patient, maybe age 4 or 5 years, what do you tell the parents about the best timing for this procedure?

D. Nuss (response): We tell them that the best age is between 6 and 12, before they go through puberty, but also when they are old enough to cooperate. The ones we have done at very young ages usually have been patients who have had other abnormalities as well. When they are 7 or 8 they do cooperate, and we like to wait until they are old enough to ensure that they will, in fact, need the repair. Before we operate, we like to hear that there has been progression of the deformity, plus all the other criteria that we look for. So 6 to 12 is an ideal age. The bone structure is very soft. They get over the operation very quickly, and they usually are back to normal activities in 6 weeks. We have patients playing soccer, basketball, we even have some playing football, which we do not recommend. I have one fellow who won the Maryland state high jump championship with the bar in place.

B. Harris (New York, NY): I would first like to extend Dr Fonkalsrud and Dr Coran thanks, and add thank you for your personal generosity in entertaining so many of

us in Norfolk to teach us this procedure. I think that is a great demonstration of professionalism.

My question is, if you take the patients in your severe group, have you had occasion to restudy any of them, and does the pulmonary function change?

D. Nuss (response): We had a preliminary look at our pulmonary function studies for up to about a year and

a half. What we found is that there is a slight improvement. So far, the improvement has not been statistically significant. Generally speaking, what we are seeing is about a 10% increase in percentiles. That is fairly constant, although there are some patients who do not improve and even the odd patient who gets worse, but we also have patients who show dramatic improvement.