Minimally invasive repair of pectus excavatum: A single institution's experience

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Background. *The Nuss repair of pectus excavatum is a relatively new, minimally invasive surgical (MIS) alternative to the traditional open "Ravitch-type" operation. We have one of the larger single-center experiences to date, and we conducted this clinical study to evaluate our early experience, emphasizing initial outcome and technical modifications designed to minimize complications.*

Methods. *A retrospective chart review was performed on 112 patients who underwent 116 pectus excavatum repairs between January 1995 and January 2001. The Nuss procedure was performed in 80 patients, and open repair was performed in 32 patients. Information about demographics, deformity, operative course, complications, and early outcome was recorded.*

Results. *Operative duration was 143 minutes for the open group and 53 minutes for the Nuss MIS group (*$P < .001$*). Blood loss was 6 mL/kg for the open group and 0.5 mL/kg for the MIS group (*$P < .001$*). Postoperative hospitalization was 3.2 days for the open group versus 3.7 days for the MIS group (*$P < .05$*).*

Conclusions. *The MIS pectus repair can be performed safely with minimal blood loss and reduced operative time. Short-term analysis of the quality of repair, including absence of preoperative symptoms, patient satisfaction, and cosmetic appearance are encouraging. (Surgery 2001;130:652-9.)*

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PECTUS EXCAVATUM IS THE MOST COMMON chest wall deformity in children. Since 1949, the traditional repair has been an open procedure based on that described by Ravitch, which involves subperichondrial resection of abnormal costal cartilages.[1] The corrected anterior sternal position may or may not be temporarily supported with a substernal bar.[2-4] Nuss et al[5] recently reported an alternative MIS technique for repair of this anomaly. This repair involves making two small incisions in the lateral chest wall, which permits an appropriately shaped convex metal bar to be secured inside the anterior chest hemicircumference. This results in elevation of the sternum with remodeling of the ribs and costal cartilages. The 10-year experience of Nuss et al validates the concept of bar repair without excision of the involved costal cartilages and shows that correction can be obtained with substantially less operative time and blood loss when compared with the more traditional repair.

Experience with this technique has been accumulating in several centers, and data regarding complications and outcomes are being compiled.[5-9] We have one of the larger single-center experiences to date, and we conducted this clinical review to evaluate our early experience, emphasizing initial outcome and technical modifications designed to minimize complications.

METHODS

All patients with pectus excavatum repaired at Children's Mercy Hospital in Kansas City, Mo, between January 1995 and January 2001 were selected for retrospective chart review. The MIS pectus bar repair was performed in 80 patients (December 1997–January 2001), and the open Ravitch-type repair, without substernal bar support, was accomplished in 32 patients (January 1995-December 1997). Patient selection for corrective repair was based on history, physical examination, plain radiographs, and selective computed tomography (CT) in both groups. The deformity classification was based on assessment of plain films, in the majority of cases, or CT, with a ratio of transverse diameter to

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anteroposterior diameter (distance between posterior sternum and anterior vertebral body) greater than 3 arbitrarily defining a severe deformity.[10]

For the open procedure, subpectoral muscle flaps were created followed by subperichondrial costal cartilage resection, and sternal osteotomy with wire or suture fixation.[1] As described earlier, the minimally invasive repair required small (2 cm) bilateral, midaxillary transverse incisions, subcutaneous tunneling and intrathoracic or extrapleural placement of a substernal convex stainless steel bar (Walter Lorenz, Jacksonville, Fla). This bar was bent to conform to the patient's anterior chest wall.[5] Lateral stabilizer bars have been used routinely since September 1999. Also, since the fall of 1999, the routine modification of a vertical subxiphoid anterior chest wall incision has been added to our repair technique (Fig 1). This modification involved the creation of a small subxiphoid pocket within the anterior mediastinum to visualize the passage of the bar at this location. Two years following their initial MIS procedure, patients are electively scheduled for removal of the bar as an outpatient operation.

Information about patient demographics, degree of deformity, operative course, complications, and initial outcome was recorded. Statistical analysis was performed using the Student *t* test. A $P < .05$ was considered significant.

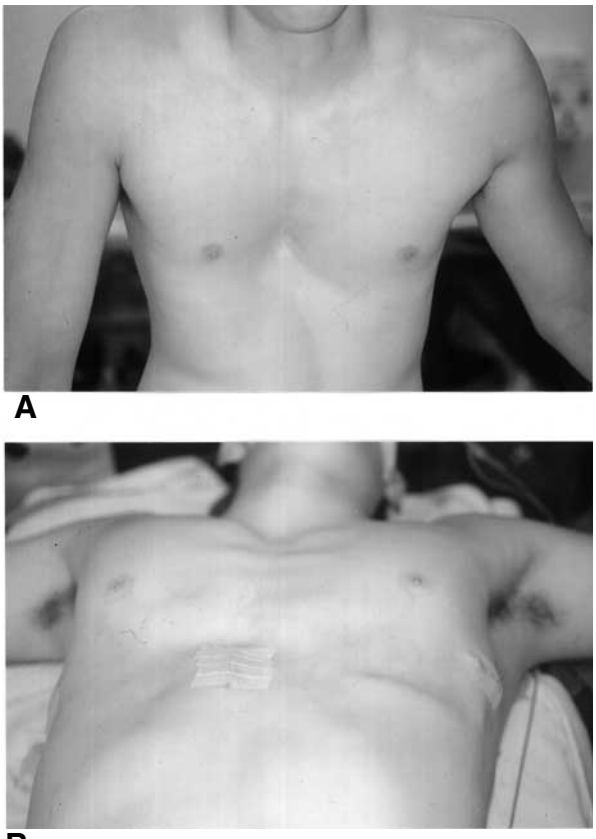

Fig 1. Illustration of our modified MIS pectus repair: **(A)** frontal view of the deformity; **(B)** frontal view after our modified MIS procedure. Note the small subxiphoid incision.

RESULTS

Of the 112 patients repaired during the 5-year period, 80 patients underwent MIS repair. In addition, 4 patients underwent reoperation for correction of a slipped bar. The 32 conventional open repairs, performed between January 1995 and December 1997, represent the last cohort of patients undergoing the open operation at our hospital and are used for comparison purposes. The mean age at the time of repair was 11.5 years for the MIS group and 9.4 years for the open group. Patient age distribution is shown in Fig 2. The clinical presentation was similar for both groups, with the majority of the symptomatic patients noting shortness of breath or exertional dyspnea. As seen in Fig 2, a significant number of teenagers (many of whom previously had declined open repair) have presented in the past 4 years after hearing about the MIS procedure. During this study period, 4 patients with a combination pectus excavatum/carinatum anomaly underwent MIS repair. In addition, 7 patients with recurrence of pectus excavatum after open correction performed prior to 1995 also underwent MIS repair, and 1 patient who underwent open correction

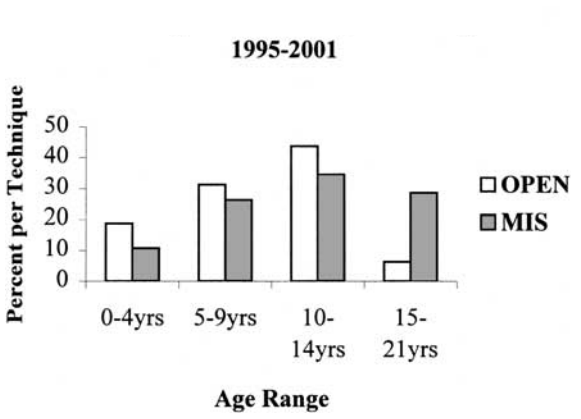

Fig 2. Age distribution of patients for open versus MIS repair of pectus excavatum.

between 1995 and 1997 underwent the MIS procedure for recurrence of his excavatum. The degree of pectus excavatum deformity was classified as severe in 76% of patients undergoing the MIS procedure and 78% of patients undergoing the open procedure.

Table I. Short-term results for open versus MIS bar repair of pectus excavatum

	Open repair (*n = 32*)	*MIS repair* (*n = 80*)	P *value*
Operative time (mean, min)	143	53	<.001
Blood loss (mean, mL/kg)	6	0.5	<.001
Length of stay (days)	3.2	3.7	<.05

The clinical course for the 2 groups was dramatically different. Table I provides clinical information for both groups. The mean operative time was 143 minutes for open repair and 53 minutes for the MIS repair ($P < .001$). The average blood loss was a mean of 6 mL/kg (mean, 200 mL) for the open operation and a mean of 0.5 mL/kg (mean, 20 mL) for bar repair ($P < .001$). Statistical significance was documented regarding reductions in operative time and blood loss utilizing the MIS procedure when comparing individual age groups as well (Fig 3). For both approaches, our results are similar to previous reports.[5-9,11-14]

There has not been a substantial difference in the subjective descriptions of postoperative pain nor in the patients' analgesic requirements. The postoperative hospitalization, averaging 3.7 days for the MIS group, was statistically longer than the average 3.2 days for the open group ($P < .05$). When individual age groups were analyzed, however, postoperative hospitalization was statistically longer for the MIS repair in patients less than 10 years old, but not statistically different for patients more than 10 years old (Fig 4).

Regardless of the type of repair, most (>90%) patients reported marked diminution in shortness of breath or exertional dyspnea. The short-term results have been good to excellent, with 76 of 80 patients in the MIS group demonstrating an appropriately corrected chest wall. These excellent results have persisted in 15 of 16 patients who have undergone the MIS procedure and removal of the substernal bar. One patient with the MIS repair developed an overcorrection resulting in a pectus carinatum. Regarding patients with combined pectus excavatum/carinatum anomalies, the pectus excavatum portion has been corrected. However, the carinatum deformity has persisted. With longer follow-up for the open procedure, good to excellent correction in 30 of 32 patients has been achieved. As mentioned, one patient in this group had an unsatisfactory persistence of his excavatum deformity and underwent correction with the MIS technique during the study period. Overall, upon questioning, patient satisfaction has been excellent.

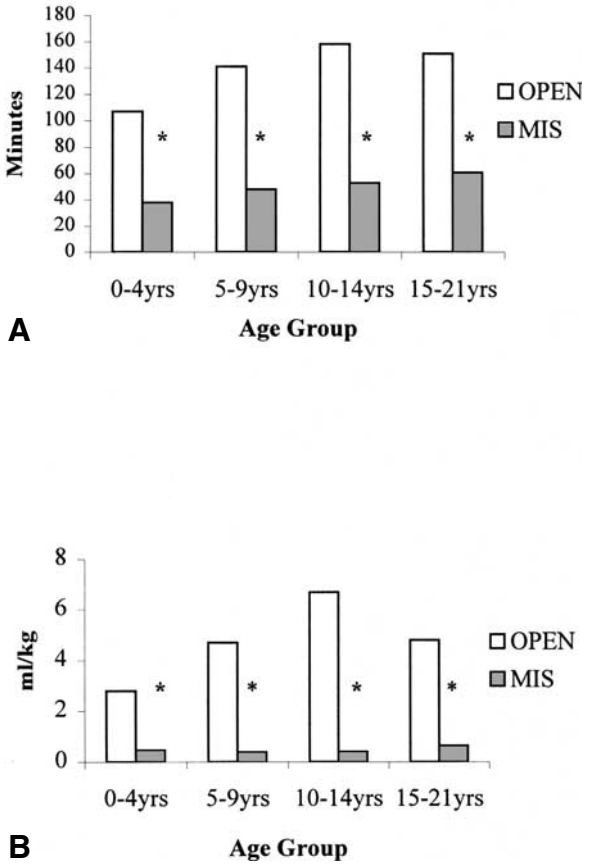

Fig 3. A, Operative time by age groups for open versus MIS bar repair of pectus excavatum. **B**, Blood loss by age groups for open versus MIS bar repair of pectus excavatum. (* $P < .001$)

The most common complication in our MIS repair series was pneumothorax, as noted in 40% of patients (Table II). The vast majority of pneumothoraces were incidental findings, as only 2 patients (2.4%) required tube thoracostomy. In 4 instances, (4.7%), the substernal bars became dislodged following the MIS operation and required re-operation. Two of these 4 bar migrations occurred in the same patient. All of the bar migrations occurred prior to the routine use of bar stabilizers and in the first 9 months of our experience. An unusual complication of hemothorax occurred in 1 patient (1.2%). Subsequent evaluation revealed a factor VII deficiency. This patient responded to tube thoracostomy and factor VII replacement and was discharged on postoperative day 4. One patient (1.2%) presented 1 month after MIS repair with noninfectious pericarditis that

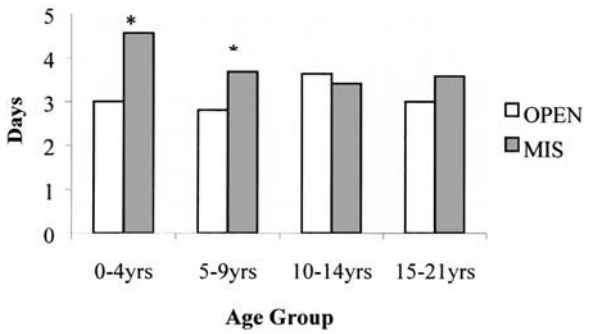

Fig 4. Length of postoperative hospitalization by age groups for open versus MIS bar repair of pectus excavatum. (*$P < .05$)

responded to pericardiocentesis and anti-inflammatory medication. Another patient (1.2%) developed an abscess around the left stabilizer bar 18 months after MIS bar placement. He underwent incision and drainage of the abscess with removal of only the stabilizer followed by 10 days of antibiotic therapy. His recovery was uneventful and the pectus bar was electively removed 6 months later. He has achieved an excellent result.

DISCUSSION

Since its introduction, the minimally invasive repair of pectus excavatum quickly has become popular with patients because of perceived improved cosmetic results from a less invasive procedure and with surgeons due to a reduced operating time. Our institution has experienced a 50% increase in patient presentation for pectus excavatum repair since introduction of this new approach. Although we acknowledge the limited duration of follow-up with the minimally invasive repair, we agree with the principles supporting this approach and are encouraged by our early results. The extent of necessary dissection, blood loss, and operative time are significantly less with this procedure.

The long-term outcomes and complications of this technique, however, are still being discovered. A recent multi-institutional review of 251 minimally invasive repairs performed at 30 centers (42% from a single institution) has attempted to identify significant complications and outcomes.[7] Although the overall complication rate in that study was 21%, compared to 11% in our single institutional study, we agree with the conclusions. Improved results can be obtained as individual surgeon experience grows.

Sixty-seven percent of our complications occurred during our first 9 months of experience. Several adjustments have been made to reduce our complication rate. The first modification was the routine use of lateral stabilizer bars to prevent rotational or lateral displacement of the retrosternal bar. Although we have experienced isolated fractures of individual stabilizers, since we began routinely using bilateral stabilizers we have not needed to reoperate prematurely for bar slippage. We believe, therefore, that the routine use of the stabilizer bars is important.

To date, the most severe complications reported from the MIS procedure have been cardiac and pericardial injury.[6-9] These significant complications have been attributed to the "blind" passage of the bar into the anterior mediastinum. We believe it is important to pass the tunneling device initially from the left chest to the right as this may protect the pericardium and heart from injury as they are displaced from the trajectory of the tunneling device's tip. However, due to recent reports of cardiac injury, some surgeons have begun to use thoracoscopy to aid in visualization of the bar as it passes behind the sternum to avoid these potential life-threatening complications. We have devised a separate modification that may achieve better visualization and security than thoracoscopy. This modification involves a small subxiphoid incision followed by blunt dissection to create a subxiphoid pocket within the anterior mediastinum. This enables direct visualization of the bar as it traverses the mediastinum without the cost and time required for thoracoscopy. The risk of cardiac and pericardial injury should be minimized with this modification. Despite having an additional small incision, our patients remain very satisfied with their cosmetic appearance.

Complications of the open procedure have been well described in the literature.[2,4,11-14] Major and minor recurrences have been reported to occur in 5% to 10% of patients from large series with adequate follow-up.[11-14] Although it did not occur in this study group, the most devastating complication resulting from the open repair is thoracic dystrophy resulting in severe restrictive lung disease. The impaired chest wall growth that occurs with this complication has been attributed to injury of the costochondral junctions and sternal growth center.[15] It has been noted primarily in children who have undergone the open procedure during their preschool years. A significant advantage of the MIS technique over the open technique is the potential to avoid this severe and often irreversible complication as excision of costal cartilages is not performed in the MIS procedure.

There is uncertainty about the optimal age for pectus excavatum repair. As mentioned above, the

Table II. Complications noted in pectus excavatum repair (January 1995-January 2001)

Complication	*Percent of patients*	
	MIS (1997-2001) n = 80	*Open (1995-1997) n = 32*
Pectus bar displacement (that required reoperation)	4.7	—
Pneumothorax (that required tube thoracostomy)	2.4	3.1
Hemothorax/pleural effusion	1.2	6.3
Pericarditis	1.2	—
Infectious complications	1.2	3.1
Bleeding requiring transfusion	—	3.1
Wound seroma	—	3.1

MIS operation may be more applicable than the open procedure for young children. In principle, the minimally invasive repair should promote more physiologic pulmonary development without the potentially restrictive defects that can develop following open repair. However, the older child is no less amenable to the Nuss repair. Twenty-three of our patients were more than 15 years old, and they have achieved good results to date. Moreover, we have obtained equally good results in 8 patients who previously had undergone open correction. This recurrent disease subset is an ideal group for the MIS procedure because a second open operation can be very difficult due to extensive scarring and loss of the normal tissue planes.

Regardless of age, there are technical issues that deserve further comment. Various instruments can be used to create the initial tunnel. Nuss et al[1] use a large Kelly clamp (V. Mueller Instrument Corp, Deerfield, Ill). We used a large Peon clamp (V. Mueller Instrument Corp) in our early experience. We have found the Walter Lorenz bar tunneler to be a more useful tool, however, especially in larger children, due to the leverage it affords for manipulating the chest wall. An important aspect of the operation is determining the sites at which the bar will exit the chest wall. Depending on the bar's shape, the exit sites define the points from which upward or outward force is delivered from the bar, similar to support at the ends of an arch. The optimal location depends on the chest wall curvature, the deformity's severity, and the bar's shape. The biomechanics are amenable to formal analysis, however, the information routinely available in the operating room is not sufficient to allow such models to be of practical benefit. In general, a bar with near uniform curvature will function optimally if the exit sites are located at points where the anterior-posterior chest measurements are maximal. This can be accomplished by inspection, or by placing the bar on the chest, prior to its insertion, and noting where the bar and chest wall begin to separate.

A final issue is assessing the need for a 2-bar repair. The severely depressed sternum with more extensive involvement along the cephalocaudal axis or the more rigid chest wall of an older teenager may be improved by a 2-bar placement. Nuss et al recommend a 2-bar repair for the patient with Marfan's syndrome.[5] Our objective criteria are limited to the eye of the surgeon: If a single-bar repair looks inadequate, then it probably is inadequate. The appropriate technical sequence and bar location for a 2-bar repair must be individualized. In general, we prefer to place both bars in position before turning them concave down, as this tends to avoid the need for sequential bar removal and reshaping.

There are no strict contraindications to using the MIS repair given the previously described technical modifications. The only relative concern is the patient with a combination excavatum/carinatum deformity. The excavatum portion will be corrected by the MIS procedure, but the carinatum aspect will persist. Despite this persistence, patient satisfaction is very high. We also have been successful in applying the MIS procedure in patients with an extremely rigid and severely deformed sternum and in patients having had previous open repairs. These patients have experienced excellent results with minimal complications. Our short-term results have encouraged us to offer this procedure to all surgical candidates with careful consideration given to each case. As with any new technique, more extensive verification of its safety and efficacy are encouraged and likely will become available in the near future.

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DISCUSSION

Dr Karen W. West (Indianapolis, Ind). This is an excellent review from a single institution experience with the Nuss or minimally invasive technique of the pectus carinatum and excavatum repairs. It walks us through modifications in the procedure that have occurred over time, usually in response to complications that have arisen such as the longer Lorenz bars that are now available, the tunneling devices, and now the addition of the stabilizing lateral devices.

This group has added the subxiphoid incision so that either the bar can be directly guided by hand or by direct visualization to prevent pericardial and cardiac injuries. Some institutions are using thorascopy and some institutions also are using a wire around the wrist and obviating the need for the lateral stabilizing bar.

Your institutional experience reminds us that there is a steep learning curve to this technique, as with any procedure. Complications should decrease over time in your experience as well as ours. What is lacking, as you point out, is long-term evaluation and follow-up. Even with the 10-plus years that Dr Nuss has been doing this procedure, new complications have arisen as this application has been broadened and extensively used by other pediatric surgeons. Is there really a perfect operation for all patients with the pectus anomaly? Or indeed should we continue to try to find the best operation for each child, teenager, and young adult that we encounter?

You indicate your last open procedure was in 1997. Does this mean that you believe that you were able to correct all anomalies with pectus malformation with this MIS procedure? You discuss 4 patients with combined anomalies with carinatum and the asymmetrical excavatum anomaly and you say that you have a satisfactory repair of the excavatum deformity but you don't comment extensively on the carinatum deformity. In our experience these are patients who we have not evaluated for this MIS procedure. Are there any patients in whom you would not offer the MIS technology? What are your exclusion criteria in this group?

Dr Miller. First, 76 out of 80 patients had excellent to good correction. The patients that we noticed less than good correction have been combined excavatum/carinatum patients. One of the 15 removed had an overcorrection with a carinatum forming. So we, too, have seen this in our practice.

The carinatum component of the anomaly is not addressed. The bar corrects excavatum. It is interesting, however, that when discussing this with patients and their families, they have subjective satisfaction with the repair. To be honest, they have not voiced interest in having a cosmetic procedure to address the carinatum defects.

Any contraindications to offering this procedure? Since we are unhappy with our combined deformities that perhaps these patients will be better served with an open procedure.

Dr Karen W. West. Have you been satisfied with the resolution of the lower rib flaring, particularly in the older teenagers? This has been the controversial area in which we have not been really satisfied with the resolution of the rib flaring over time. Have you ever left the bars in for longer than 2 years to see if the rib flaring will resolve over time?

Dr Miller. As far as flaring of the ribs, most of our patients seem to be very satisfied. We have not left the bar in longer than two years, however, this is something that we are still resolving. At this time we have been relatively strict with taking the bar out at two years.

Dr Karen W. West. What are you currently using for pain control? You mention that there is no big difference in the pain control issues for either the open versus the MIS repair but you don't comment on what you are using.

Dr Miller. Our pain control is predominantly by epidural catheter. We offer this to every patient. However, not all families or patients actually consent to this and usually end up with PCA catheters.

Dr Karen W. West. You also comment in your manuscript you are now seeing 50% more patients than you used to see. Is this really the power of the Internet or are we really seeing more patients with this anomaly over time?

Dr Karen W. West. What preoperative evaluations are you employing? You talk about the CT scan in your man-

uscripts. But we find that our insurance companies are still requiring either pulmonary functions or echo evaluations to ascertain whether this is being done for other than cosmetic reasons.

Dr Miller. Most of our patients undergo preoperative CT scan. Several patients have some pulmonary function tests, but this isn't absolute. It seems that in our area the insurance companies are satisfied if we can document that exercise-induced intolerance is present in our patients.

Dr Karen W. West. This certainly is a well-written manuscript that continues to add to the growing volumes of literature concerning this technique.

Dr Juda Z. Jona (Chicago, Ill). A couple of comments. I was the witness to when Dr Nuss, with his own hands, perforated the patient's heart in what was a "minimally invasive" procedure that ended up being a maximally threatening procedure. This is something to consider.

When one looks at the anatomy of pectus excavatum in most of these children, the cardiac chambers are displaced to the left and pushed anteriorly such that they are at the level of the sternum. Dr Nuss and everybody else, including this presenter, pass the bar from right to left. I think this is a big mistake. Because you cannot bypass the sternum without at least grazing the heart or getting awfully close to it. Probably a safer approach would be to go from left to right and with a finger ascertain that the heart is not in the way.

The second thing is the fact that when you apply this procedure to teenagers, the deformity is markedly fixed and it takes an enormous amount of pressure to first correct it and then maintain it. My question to the author concerns when the duration of analgesia is much prolonged compared with those that have the open procedure. It is my experience that 7 to 10 days following the open operation, patients don't really need much medication at all, while with the bar I suspect that it takes a very long time before there is no need for analgesia.

Dr Miller. Regarding Dr Jona's comment about passing the bar from left to right, we also have made that modification. We feel that with this change it should make a difference which direction to pass the bar because you are effectively pushing the heart out of the way. However, we had previously changed our direction, thinking that the trajectory of the bar would protect the heart by coming from left to right.

As far as actual duration of analgesics, most of our hospital stay, as you can see, is 2.5 to 4 days. Patients do go home on postoperative pain management, however, and I do not believe we have studied that adequately for me to comment.

Dr Dennis P. Lund (Madison, Wis). This is one of a number of single institution reports showing good results with this procedure. I am a little bit worried about this being a procedure that is easy for surgeons but hard for patients.

In doing pectus repairs for more than a dozen years now using the technique that was developed by Welch at the Children's Hospital in Boston, I have never transfused a patient. And Welch in fact reported on more than 1,000 patients that he did there without a transfusion.

The thoracic dystrophy issue, which again is a major problem, is more related to doing younger children and also to not taking care with how you do your rib resections. I think that if you protect the perichondrial sheets it is unlikely that you will get the thoracic dystrophy problem.

The question I have for the author concerns the longer length of stay presumably due to pain control. Has this prompted you to move toward doing children at a younger age because the pain is a bigger problem for older children?

The second question is related to when you will allow your patients to go back to contact sports. When I do children with the open technique, even if we put in a stabilizer bar, usually I get that stabilizer bar out by about 6 months and I will let children go back to contact sports. The question here is, will you allow your patients to play hockey or football with this Lorenz bar in before you take it out at 2 years?

Dr Miller. We do avoid or actually ask our patients to avoid heavy contact sports—that is, football, hockey, wrestling—while they have the bar in place. I know our patients entertain lesser contact sports, however.

Dr Jay L. Grosfeld (Indianapolis, Ind). There is no doubt that the Nuss application to pectus excavatum repair has been a major contribution. The concept of the procedure is to remodel the soft cartilage using the upward push of the stainless steel bar on the under surface of the sternum as a form of internal pressure orthotics. This minimally invasive procedure has a learning curve and also has a downside as it results in significant postoperative pain requiring higher doses of analgesics than the open technique.

I have a few questions for the authors. There were a number of patients in your series that were less than 4 years of age at the time of operation. What were the indications for surgery in this young age group? Have you changed the method of delivering pain medication postoperatively? The severe pain that the children experience with the Nuss procedure has led us to uniformly place an epidural catheter in the operating room prior to the procedure to minimize pain in the first 2 to 3 days postoperatively. Have you employed the Nuss technique on patients with connective tissue disorders such as Marfan's syndrome, which commonly is associated with a chest wall defect? Frequently, cardiac surgeons would like to have the defect repaired prior to performing open-heart surgery in these patients. It has been our experience, however, that because of the connective tissue disorder, the minimally invasive technique may overcorrect the sternal position significantly and converts a patient with pectus excavatum to one with pectus carinatum. This has required very early removal of the support bar, as early as within 6 months of the procedure. Dr Nuss has a similar experience in his own practice.

Finally, considering the fact that pressure orthotics seems to work in remodeling the chest when the cartilage is soft and pliable in the young child, would you consider using external compressive orthotics as a non-operative approach to repairing pectus carnatum defects?

Dr Miller. The indications for the several patients who underwent excavatum repair at a very young age. These patients had severe deformities with a lot of pulmonary dysfunction and I think we were a little pressed based on our pulmonologists who thought our repair might contribute to improving those patients' pulmonary functions.

Although we have not had a patient with Marfan's disease, carinatum defect is an interesting question and an extra-thoracic brace or orthotic is an interesting application of a potential future approach to this defect. We have had two patients where we have used two bars. In those patients they had very long defects, and the use of the 2 bars were after placing the first bar and being unsatisfied with the intraoperative result.

Dr David S. Mulder (Montreal, Quebec, Canada). One more question. Is there an upper age limit to consider?

Dr Miller. I don't have a good answer to that. However, I do know that some of the operators at our institution believe it is possible to offer this to adults. But it hasn't been done in adults at this point that I know of.