MINIMALLY INVASIVE REPAIR OF PECTUS EXCAVATUM: A SINGLE INSTITUTION'S EXPERIENCE.

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ABSTRACT

Background: The Nuss repair of pectus excavatum is a relatively new, minimally invasive (MIS) alternative to the traditional open "Ravitch-type" operation. With one of the larger single center experiences to date, 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 of 112 patients who underwent 116 pectus excavatum repairs between January 1995 and January 2001 was performed. 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 min for the open group and 53 min for the MIS group ($p<0.001$). Blood loss was 6ml/kg for the open group and 0.5ml/kg for the MIS group ($p<0.001$), and post-operative hospitalization was 3.2 days for the standard group vs. 3.7 days for the MIS ($p<0.05$).

Conclusions: The minimally invasive 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 quite encouraging.

Introduction Pectus excavatum is the most common chest wall deformity in children. Since 1949, the standard repair has involved 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. recently reported an alternative, minimally invasive technique for repair of this anomaly.5 This repair involves two small incisions in the lateral chest wall which permit an appropriately shaped convex metal bar to be secured inside the anterior hemicircumference of the chest. This results in elevation of the sternum with remodeling of the ribs and costal cartilages. Their 10-year experience 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 to 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 With one of the larger single center experiences to date, 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 of 1995 and January of 2001 were selected for retrospective chart review. The minimally invasive 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 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 subperichondral costal cartilage resection, and sternal osteotomy with wire or suture fixation.1 As described earlier, the minimally invasive repair required small (2cm), bilateral, midaxillary transverse incisions, subcutaneous tunneling and intrathoracic or extrapleural placement of a substernal convex stainless steel bar (Walter Lorenz, Jacksonville, FL). 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.

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's t test. A $p< 0.05$ was considered significant.

Results

Of the 112 patients repaired during the five-year period, 80 patients underwent MIS repair. In addition, four patients underwent reoperation for correction of a slipped bar. The 32 conventional open repairs, performed between January of 1995 and December of 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 Figure 2. The clinical presentation was similar for both groups with the majority of the symptomatic patients noting shortness of breath or exertional dyspnea. As is seen in Figure 2, a significant number of teenagers (many of whom had previously declined open repair) have presented in the last four years after hearing about the MIS procedure. During this study period, four patients with a combination pectus excavatum/carinatum anomaly underwent MIS repair. In addition, seven patients with recurrence of pectus excavatum after open correction performed prior to 1995 also underwent MIS repair, and one patient who underwent open correction 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.

The clinical course for the two groups was dramatically different. Table 1 provides clinical information for both groups. The mean operative time was 143 minutes for open repair and 53 minutes for the MIS repair ($p<0.001$). 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 ($p<0.001$). Statistical significance was documented regarding reductions in operative time and blood loss utilizing the MIS procedure when comparing individual age groups as well (Figure 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 analgesic requirements of the patients. The postoperative hospitalization, averaging 3.7 days for the MIS group, was statistically longer than the average 3.2 days for the open group ($p<0.05$). When individual age groups were analyzed, however, postoperative hospitalization was statistically longer for the MIS repair in patients under 10 years of age, but not statistically different for patients over 10 years of age (Figure 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 76/80 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 the 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 30/32 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.

The most common complication in our series of MIS repairs was pneumothorax which as noted in 40% of patients (Table 2). The vast majority of pneumothoraces were incidental findings, as only two patients (2.4%) required tube thoracostomy. In four instances, (4.7%), the substernal bars became dislodged following the MIS operation and required re-operation. Two of these four instances of bar migrations occurred in the same patient. All of these 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 one 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 four. One patient (1.2%) presented one month after MIS repair with noninfectious pericarditis that 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 six months later. He has achieved an excellent result.

Discussion

Since its introduction, the minimally invasive repair of pectus excavatum has quickly become popular with patients due to perceived improved cosmetic results from a less invasive procedure and with surgeons due to a reduced operating time. A 50% increase in patient presentation for pectus excavatum repair has been appreciated at our institution 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 different centers (42% from a single institution) has attempted to identify significant complications and outcomes.7 While the overall complication rate in that study was 21%, compared to 11% in our single institutional study, we are in agreement 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. Therefore, we believe that the routine utilization 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 tip of the tunneling device. 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 allows direct visualization of the bar as it traverses the mediastinum without the cost and time required for thoracoscopy. With this modification, the risk of cardiac and pericardial injury should be minimized. Despite having an additional small incision, our patients remain very satisfied at their cosmetic appearance.

Complications of the open procedure have been well described in the literature.2,4,11-14 Major and minor recurrences have both been reported to occur in 5 –10% of patients from large series with adequate follow-up. 11-14 While not occurring in this study group, the most devastating complication resulting from the open repair is that of 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.14 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 avoidance of 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 repair of pectus excavatum. As mentioned above, the 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 over 15 years of age, and they have achieved good results to date. Moreover, we have obtained equally good results in eight patients who had previously undergone open correction. This subset of recurrent disease is an ideal group for utilization of the MIS procedure as 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 deserving further comment. Various instruments can be used to create the initial tunnel. Nuss et al. use a large Kelly clamp.1 In our early experience, a large Peon clamp was employed. However, we have found the Walter Lorenz bar tunneler to be a more useful tool, 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 actual shape of the bar, the exit sites define the points from which upward or outward force is delivered from the bar, similar to support at two ends of an arch. The optimal location depends on the curvature of the chest wall, the severity of the deformity, and the actual shape of the bar. The biomechanics are quite 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 two-bar repair. The severely depressed sternum with more extensive involvement along the cephalo-caudal axis or the more rigid chest wall of an older teenager may be improved by the placement of two bars. Nuss et al. recommend a two-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 two-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.

With the previously described technical modifications, there are no strict contraindications to the MIS repair. The only relative concern is the patient with a combination excavatum/carinatum deformity. With the application of the MIS procedure to these chest wall anomalies, the excavatum portion will be corrected, but the carinatum aspect will persist. Despite this persistance, patient satisfaction is very high. In addition, we have been very 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 will likely become available in the near future.

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