Hybrid Technique for Repair of Recurrent Pectus Excavatum After Failed Open Repair

Kevin N. Johnson, MD, Dawn E. Jaroszewski, MD, MennatAllah Ewais, MD, Jesse J. Lackey, CSFA, Lisa McMahon, MD, and David M. Notrica, MD

Divisions of General Surgery and Cardiothoracic Surgery, Mayo Clinic, Arizona, and Division of Pediatric Surgery, Phoenix Children's Hospital, Phoenix, Arizona

Background. **Successful repair of recurrent pectus excavatum (PE) after failed open procedure has been reported using minimally invasive repair (MIRPE) and open approaches. Neither approach alone may be adequate for some patients. A hybrid technique for repair is presented for revision of recurrent PE.**

Methods. **A retrospective review of adults undergoing repair for recurrent PE after prior open repair from January 2010 to June 2014 was performed.**

Results. **Seventy-three adult patients underwent repair for recurrent PE, with 48 patients (65.8%) undergoing repair for recurrence after at least one prior open PE repair. Mean patient age was 34.5 years (range, 19 to 54 years); mean Haller index was 4.7 (range, 2.8 to 14.7). Fourteen (29%) recurrences with adequate chest wall pliability and no malunion were repaired with MIRPE alone; 34 patients (71%) underwent a hybrid procedure for repair (20 for PE recurrence alone; 14 for PE with acquired thoracic dystrophy). All had at least two support bars placed, and 11 patients (23%) had three bars placed. Mean hospitalization for MIRPE was 5 days, for hybrid was 7 days, and for hybrid because of acquired thoracic dystrophy was 10 days. One patient died of unexpected out-of-hospital arrest; there was one emergent conversion to open sternotomy for bleeding.**

Conclusions. **Most recurrent PE may be repaired with excellent results and minimal complications. Those with adequate chest pliability and no malunion are candidates for MIPRE alone. A hybrid procedure with thoracoscopic support bars combined with sternal elevation, multiple open osteotomies, and chest wall fixation is appropriate for recurrences associated with malunion or fixation of the anterior chest and failure to lift with MIRPE.**

(Ann Thorac Surg 2015;99:1936–44)

Recurrence after open pectus excavatum (PE) repairs such as the Ravitch procedure have been reported to occur in 2% to 20% of patients [1–8]. The frequency may be underreported as many patients with late recurrence fail to follow up with their surgeon or may seek medical care at another center for revision. Repair of recurrent PE after open surgery is often complex with unique problems [2, 5, 9–13]. Extensive calcification, ossification, and fusion of the anterior chest wall may prevent adequate sternal elevation (Fig 1). Osteotomies of the sternum, sternocostal junctions, and lateral ribs may be necessary to mobilize the defect [1, 14]. Minimally invasive repair of PE (MIRPE) may be more difficult as a result of chest rigidity, and bar displacement is more likely [3, 8, 15]. Recurrence may also occur because of osteonecrosis, malunion, and pseudoarthrosis with resulting instability (Fig 2) [2, 10, 13–16]. For these cases, MIRPE alone will fail. Excision of the fibrous malunion with stabilization is necessary [11, 13, 17].

Both open and minimally invasive techniques have been described for repair of recurrent PE, and both approaches offer advantages [3, 8, 12, 14, 18, 19]. A hybrid application of both techniques may be advantageous to achieve good outcomes in selected patients. A review of our repairs of recurrent PE after prior open repair is presented as well as a description of our current hybrid technique.

Patients and Methods

Institutional review board approval was obtained, and a retrospective review of all patients undergoing repair of PE by a single primary surgeon between January 2010 and June 2014 was performed. Follow-up of patients was performed through January 2015. Patients were determined to have recurrent PE based on medical records. Those with purely cosmetic prior surgeries (pectus implants or breast augmentation) without attempt to correct the pectus defect were excluded. For comparison, first-time PE patients repaired by primary MIRPE without additional surgical procedures were evaluated.

Patient demographics, type of previous repair, and information regarding the recurrent defect and symptomatology were abstracted from clinical notes. Patients underwent echocardiographic, pulmonary function, cardiopulmonary exercise testing and other evaluations for documentation of symptoms and evidence for cardiac compression or cardiopulmonary limitations. Operative

Accepted for publication Feb 26, 2015.

Address correspondence to Dr Jaroszewski, 5777 E Mayo Blvd, Phoenix, AZ 85054; e-mail: jaroszewski.dawn@mayo.edu.

Published by Elsevier

0003-4975/$36.00
http://dx.doi.org/10.1016/j.athoracsur.2015.02.078

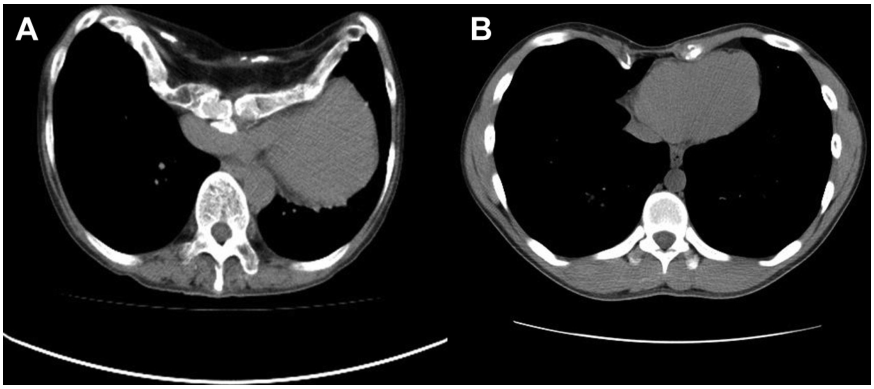


Fig 1. Computerized tomography shows areas of (A) extensive calcification along the costosternal junctions and (B) malunion at costosternal junctions after a prior open pectus excavatum repair.

notes from the patient's initial surgery at outside institutions as well as initial Haller index and postoperative complications were obtained when available. Information regarding the operation at Mayo Arizona including approach (open, minimally invasive, or a combination of both), operative time, length of stay, and complications were obtained from hospital records. Initial indications for repair of recurrent PE were similar to those for primary repair and included a Haller index greater than 3.2 and those with symptomatology. Based on early experience with recurrent PE, indications for repair were expanded to include patients with symptomatic areas of nonunion, pseudoarthrosis, chest wall hernia, or other evidence of chest wall instability even if they did not meet criteria based on the severity of their defect.

An algorithm to our approach for recurrent open patients is presented in Figure 3. The majority of patients underwent attempted MIRPE. Planned reopening and revision of prior open resection was only performed in patients with known sites of malunion, pseudoarthrosis, chest wall hernia, or extreme fixation owing to thoracic dystrophy with these undergoing planned hybrid procedure [10, 11]. The analysis of patients operated on with recurrent PE and recurrent PE with acquired thoracic dystrophy (ATD) were done separately owing to the added complexity of these high-risk patients [11]. Acquired thoracic dystrophy was defined as significant growth failure and extensive ossification as a result of excessive excision of chest cartilage during PE repair at a young age [11, 20].

Procedure

POSITIONING. All patients are administered intravenous antibiotic prophylaxis before initiation of the procedure. General anesthesia with double-lumen intubation is performed. A transesophageal echocardiogram probe is placed for continuous evaluation of cardiac function, monitoring for adverse events throughout the case, and for relief of cardiac compression. The patient is placed supine with two longitudinal 5-inch rolls under the back parallel to the spine. Arms are placed with slight elbow flexion, padded, and tucked in at the sides. Groins are

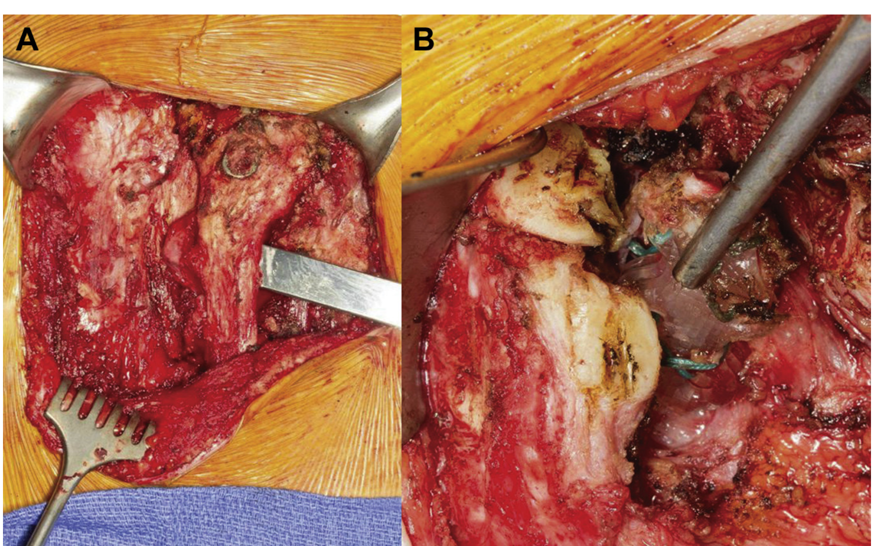
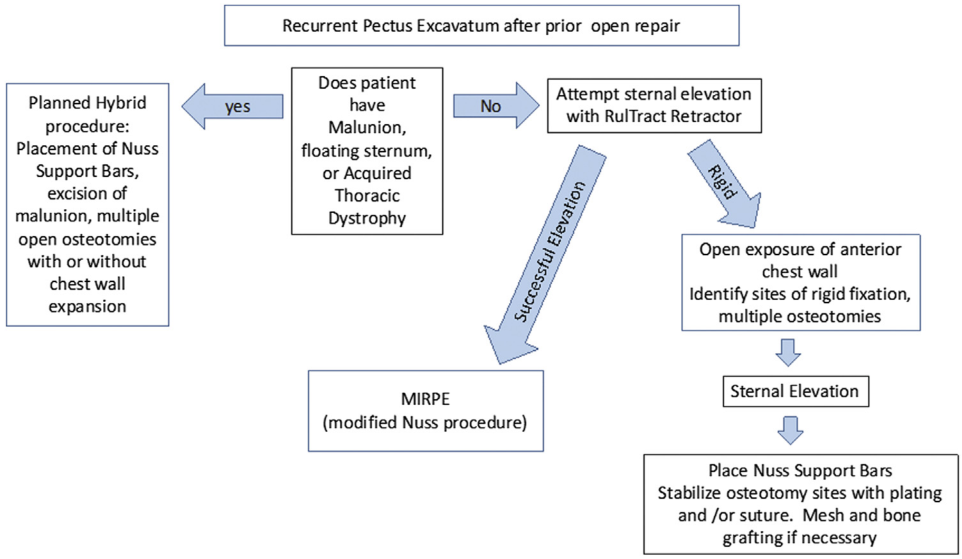


Fig 2. Intraoperative photographs of 2 patients with (A, B) sites of fibrotic malunion after prior failed, open pectus excavatum repair. These areas are (A) debrided back until viable cartilage is identified, and (B) foreign materials are removed to prevent further fibrosis and reaction.

GENERAL THORACIC

Fig 3. Algorithm to our operative approach for recurrent open patients. (MIRPE = minimally invasive repair of pectus excavatum.)



prepped and draped for possible emergent groin access or cardiopulmonary bypass. This elevated supine chest positioning facilitates access to both the anterior and lateral aspects of the chest wall for placing and affixing bars.

THORACOSCOPY. Typical bilateral 3- to 4-cm MIRPE incisions are made at the inferolateral pectoral borders. Incisions are positioned to allow access to the intercostal spaces adjacent to the defect. Submuscular pockets are developed using electrocautery. The pectoralis and lateral muscles are lifted off the anterior and lateral chest wall to prevent trapping of chest muscles under the support bars. Initially a 5-mm port is placed through the right incision, and carbon dioxide insufflation to 5 to 8 mm Hg pressure is used. A 5-mm flexible endoscope (Olympus 5-mm Endoeye Flex 5; Olympus, Central Valley, PA) is introduced for thoracoscopic visualization. Often extensive pleural adhesions are encountered, requiring electrocautery and blunt dissection adhesiolysis. An additional 5-mm port is placed inferiorly above the right diaphragm.

Attempted Sternal Elevation

Elevation with the Rultract Retractor (Rultract Inc, Cleveland, OH) is then attempted. Two-millimeter incisions are placed on either side of the sternal defect using the patient's previous open scar when possible. A perforating bone clamp (Lewin Spinal Perforating Forceps, V. Mueller NL6960; CareFusion Inc, San Diego, CA) is inserted into the sternum. The Rultract retractor with an attached extension arm is bedside mounted at the level of the upper sternum on the left side. The Rultract is then attached to the clamp, and an attempt is made at sternal elevation (Fig 4).

Sternal Elevation Achieved

If the sternal elevation is achieved and there are no suspected areas of malunion or chest wall instability present, an MIRPE is performed as follows. After sternal elevation, adhesiolysis of remaining pleural and mediastinal adhesions is performed. A Lorentz dissector (Biomet Micro-Fixation, Jacksonville, FL) is passed across from a right anterior chest interspace, under the sternum, and out the contralateral interspace. FiberWire (Arthrex Inc, Naples, FL) is then attached to the end before removal to guide the implant bar placement. Thoracoscopic-guided Nuss bar placement is then performed, and the process is repeated to place two to three bars. The decision as to the

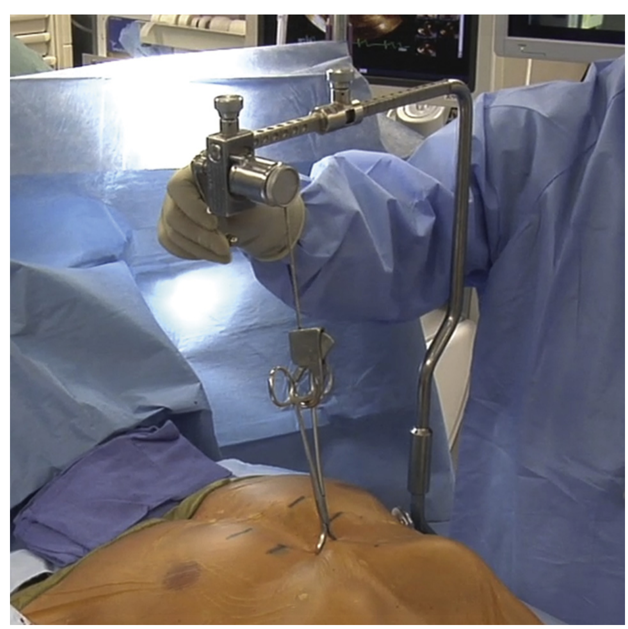


Fig 4. A Rultract (Rultract Inc, Cleveland, OH) table-mounted retractor is used for attempting chest wall elevation at initiation of case and with revision of open repair during the hybrid reconstruction.

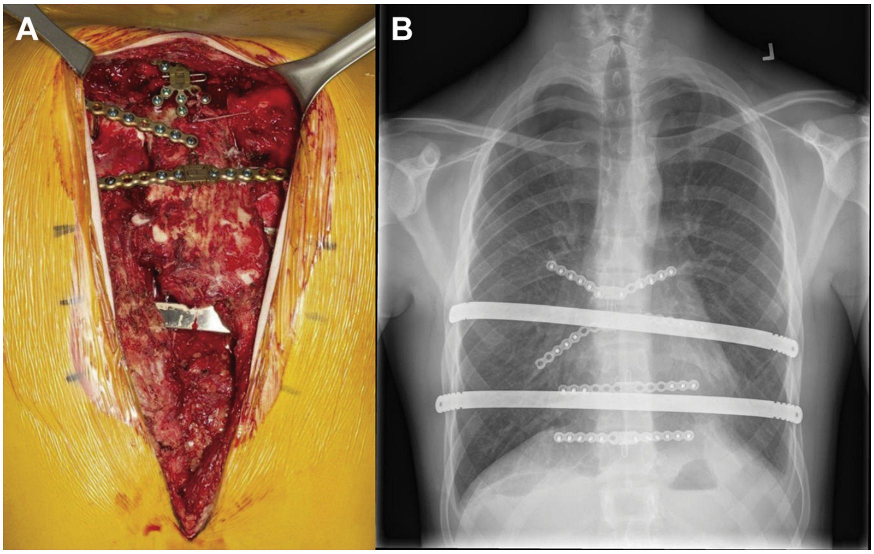


Fig 5. Titanium plating and sternal support bars are used and shown in (A) intraoperative photographs and (B) postoperative chest roentgenogram after hybrid reconstruction.

number of bars needed is made during the operation based on the deformity. The first bar is positioned in the interspace at the superior aspect of the defect. A second bar is then placed either one or two intercostal spaces below. If a lower chest wall defect persists, a third bar is placed. Bars are sized and shaped to best correct the patient's defect. We prefer slightly shorter bar lengths and minimize the lateral extension of the bar around the chest. Bars are custom bent and shaped, and aluminum sizers are used to estimate bar length and shape. The sizer is placed across the chest and bent to allow 2 to 3 cm of curvature around the lateral aspect of the chest. Bars are rotated into place with the sternum still elevated by the Rultract to minimize stripping of the intercostal space laterally. Bilateral circumferential fixation of the bars around the rib using FiberWire is performed as previously described [21]. Two or three sites of fixation are performed bilaterally for each bar.

Failure of Sternal Elevation

If forced sternal elevation cannot elevate the chest anteriorly, or if malunion or sternal floating is evident, the incision from patient's previous open procedure is opened and dissection is taken down to the bony chest wall, typically elevating the pectoris muscles. Sites of calcified restriction or malunion are identified. Areas of pseudoarthrosis and malunion are excised until viable cartilage or bone is identified. Osteotomies are performed of the sternum and fused rib, costochondral, or sternochondral junctions. If cartilage and perichondrium remain, a perichondrial-preserving cartilage wedge resection is performed as necessary. These techniques are similar to those used in the Fonkalsrud repairs, but are limited only to areas that will not elevate and for sites with persistent malformation after elevation [3, 5, 22]. For many patients, osteotomies of the sternum and fused ribs using bone chisels or powered bone saw are required to free the sternum. Small resections and osteotomies are continued until elevation of the anterior chest wall to the proper position is obtained. The Rultract is left in position assisting elevation during this time. The Nuss bars under the anterior chest stabilize the anterior chest wall from below.

Titanium sternal plating (Biomet Microfixation; and DePuy Synthes, West Chester, PA) and FiberWire fixation is used to approximate and stabilize sites of costocartilage or rib to the sternum anteriorly (Fig 5). Plates are chosen based on length and shape to best accommodate the fixation. Multiple plates are used, and FiberWire is used to attach to the sternum when required. For areas of extensive deformity with osteonecrosis or chest wall hernia, use of cadaveric bone graft, methyl methacrylate, and biologic mesh sheeting (XCM Biologic Tissue Matrix, DePuy Synthes, Inc, West Chester, PA; and Strattic Reconstructive Tissue Matrix, LifeCell Corp, Bridgewater, NJ) may be required for repair. These techniques are described in prior publications [10, 11].

Once the chest wall deformity is completely corrected, the pectoralis muscle and fascia, as well as the rectus abdominis muscle and fascia are reattached. The incisions are closed with layered absorbable suture. In some patients, approximation of the muscle cannot be accomplished despite complete mobilization, and biologic mesh is used to bridge the gap (Fig 6). The sternal clamp is removed, and a single approximating stitch is placed on the sites of the bone clamp insertion. A 16F chest tube is placed through the lower port site on the right and left in place for at least 24 hours or until drainage is less than 300 mL over 24 hours as is our standardized practice. An additional chest tube is placed on the left if extensive intrathoracic adhesions were encountered on the left. Postoperatively, either epidural or On-Q PainBuster

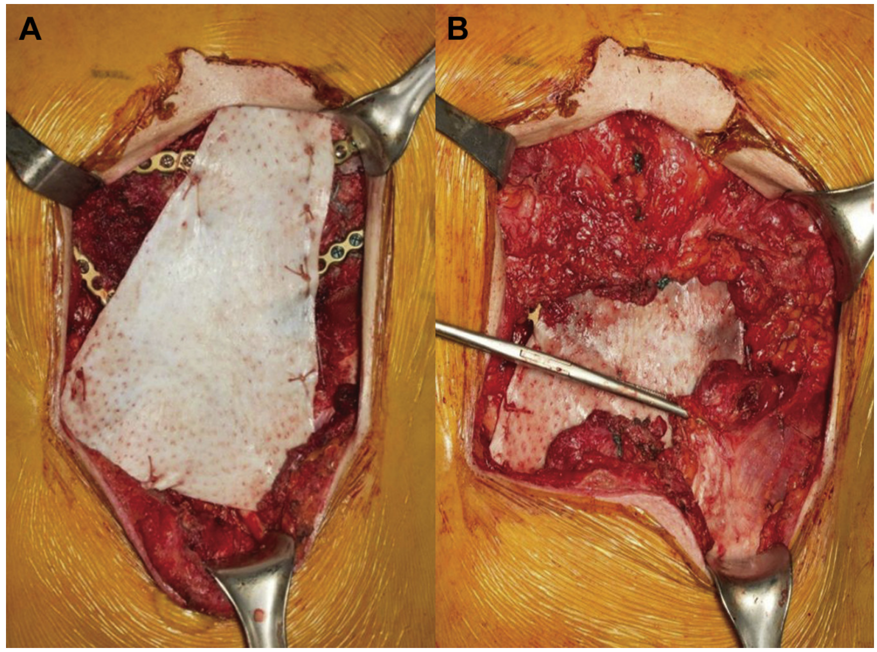


Fig 6. (A, B) Biologic mesh is used to cover titanium plating when mobilized muscle flaps are inadequate to provide complete coverage.

Catheters (Halyard Health, Irvine, CA) are used for pain control with narcotic pain medication. Our practice is to leave the pectus support bars in place for 3 years. Titanium plating is not routinely removed unless there are issues such as plate loosening, infection, or pain.

Results

During the study period, a total of 290 adult patients (>18 years) underwent PE repair, with 217 primary repairs and 73 (25%) for recurrent PE. Of these 73 patients with recurrent PE, the 48 (65.7%) who had undergone at least one prior open repair composed the study group. The demographics and prior operations types are shown in Table 1.

The mean patient ages were 34.5 years (median, 32 years; range, 19 to 54 years), with a mean severity index of recurrence of 4.7 (median, 4.4; range, 2.8 to 14.7). The most common presenting symptoms were dyspnea (89.6%), chest pain (85.4%), and inability to keep up with their peers in physical activity (83%). A complete list of presenting symptoms is reported in Table 2. Twenty-eight patients underwent cardiopulmonary exercise testing before surgery, with 82% (23 of 28) being classified as low or very low exercise capacity with a decreased maximal oxygen consumption, oxygen consumption to heart rate ratio, and oxygen consumption to carbon

Table 1. Patient Demographics

Variables	MIRPE	Simple Hybrid	Thoracic Dystrophy
Total patients	14 (29.2%)	20 (41.6%)[a]	14 (29.2%)
Age, y, mean (range)	31.6 (20–51)	34.85 (19–50)	37.1 (21–54)
Sex			
Male	10 (71.4%)	15 (75%)	13 (92.9%)
Female	4 (28.6%)	5 (25%)	1 (7.1%)
Family history	2 (14%)	1 (5%)	4 (28.6%)
Haller index, mean (range)	4.9 (3.3–8.3)	4.1 (2.8–6.5)	5.5 (3.3–14.7)
Types of previous surgery			
Ravitch	9 (64.3%)	17 (85%)	12 (85.7%)
Leonard	2 (14.3%)	1 (5%)	0
Sternal Flip	0	1 (5%)	0
Ravitch and Nuss	3 (21.4%)	1 (5%)	2 (14.3%)

[a] Includes patient with sternotomy who was repaired with revision Ravitch and support bar placement.

MIRPE = minimally invasive repair of pectus excavatum.

Table 2. Symptoms at Presentation

Symptoms	MIRPE	Simple Hybrid	Thoracic Dystrophy
Total patients	14 (29.2%)	20 (41.6%)[a]	14 (29.2%)
Dyspnea	11 (78.6%)	19 (95%)	13 (92.9%)
Tachycardia/palpitations	8 (57%)	13 (65%)	11 (78.6%)
Difficulty keeping up with peers	11 (78.6%)	16 (80%)	13 (92.9%)
Chest pain	12 (85.7%)	19 (95%)	10 (71.4%)
Asthma	2 (14%)	5 (25%)	7 (50%)
GERD	1 (7%)	4 (20%)	4 (28.6%)
Psychiatric			
Anxiety	5 (35.7%)	8 (40%)	3 (21.4%)
Depression	1 (7%)	8 (40%)	4 (28.6%)

[a] Includes patient with sternotomy that was repaired with revision Ravitch and support bar placement.

GERD = gastroesophageal reflux disease; MIRPE = minimally invasive repair of pectus excavatum.

dioxide ratio. Forty-two patients had preoperative echocardiography, with 21 (50%) demonstrating right ventricular compression. Seven patients had a family history of PE (14.6%), but no patients had Marfan syndrome.

The majority of patients (34 of 48, 70.8%) underwent a hybrid-type procedure for repair. One patient underwent conversion to sternotomy when excessive bleeding occurred during thoracoscopic takedown of mediastinal adhesions. He was subsequently repaired after closure of the sternotomy with a hybrid procedure. This patient was excluded from comparison analysis in Table 3 by virtue of being an outlying variable. An MIRPE alone successfully corrected 14 patients (29%). Lysis of adhesions increased operative time, blood loss, and the hospital stay in this group of revision MIRPE compared with our primary MIRPE cases during this period (mean operative time, 165 minutes versus 115 minutes; blood loss, 147 mL versus 54 mL). The hybrid approach was required for osteotomies as a result of calcification and rigidity in 15 patients (15 of 34, 44%) and stabilization of malunion in 16 patients (16 of 34, 47%). Titanium plating was added in 26 of the hybrid repairs, muscle advancement flaps were performed in 28 patients, and placement of biologic mesh was performed in 20 patients. All patients had at least two pectus support bars placed, and 11 (23%) required three bars.

Mean operative times increased with greater complexity of the revision as shown in Table 3. Complications are reported in Table 4, with the most significant complication being the sudden, unexpected death of a 22-year-old woman on postoperative day 10. The patient experienced an out-of-hospital arrest with hypoxia, pulseless electrical activity, and unsuccessful resuscitation. Another patient was readmitted after

Table 3. Operative and Hospitalization Information

Variables	MIRPE	Simple Hybrid	Thoracic Dystrophy
Total patients	14	19[a]	14
Number of bars used			
2 bars	9 (64.3%)	16 (84.2%)	11 (78.6%)
3 bars	5 (35.7%)	3 (15.8%)	3 (21.4%)
Operative time (min), mean	165	295	397
Median (range)	150 (60–308)	289 (147–443)	399 (246–545)
Titanium plating	0	13 (68%)	13 (92.9%)
Biologic mesh placement	2 (14.3%)[b]	8 (42%)	12 (85.7%)
Poly methyl methacrylate (PMMA)	0	1 (5%)	2 (14.3%)
Pectoralis muscle/rectus abdominis advancement flap	2 (14.3%)	14 (73.7%)	13 (92.9%)
Blood loss (mL), mean	147	521	696
Median (range)	50 (25–700)	500 (100–1,000)	700 (400–1,000)
Length of hospital stay (days), mean	5	7	10
Median (range)	5 (4–8)	6 (4–15)	7 (6–24)

[a] Patient requiring conversion to open sternotomy excluded from analysis; OR time 178 minutes, estimated blood loss 1,300 mL, and length of hospital stay 8 days. [b] Mesh placed as barrier between breast implants and support bars [23].

MIRPE = minimally invasive repair of pectus excavatum.

Table 4. Patient Morbidities and Mortality

Variables	MIRPE	Simple Hybrid	Thoracic Dystrophy
Total patients	14	20	14
Pneumothorax requiring chest tube insertion	0	1 (5%)	0
Infection			
Pneumonia	0	2 (10%)	2 (14.1%)
Urinary tract	0	0	0
Wound infections	1 (7.1%)	2 (10%)	0
Prolonged respiratory failure with tracheostomy	0	0	3 (21.4%)
Blood loss requiring blood transfusion	0	5 (25%)[a]	6 (42.9%)
Readmission or reintubation for narcosis or aspiration	1 (1.7%)	1 (5.3%)	1 (7.1%)
Severe constipation/ileus	0	1 (5.3%)	1 (7.1%)
Reoperation and revisions			
Minor revision cartilage shaving, other	0	2 (10.5%)	0
Bar displacement	1 (7.1%)	0	0
Major revision procedures	1 (7.1%)	3 (15%)	1 (7.1%)
Mortality	0	1 (5%)	0

[a] One patient requiring conversion to open sternotomy with 1,300 mL of blood loss did not undergo transfusion secondary to religious beliefs.

MIRPE = minimally invasive repair of pectus excavatum.

cardiopulmonary arrest from an accidental narcotic overdose on postoperative day 18. He was stabilized and discharged to home. Overall complications were higher in the ATD group.

Patient follow-up averaged 21.9 months (range, 6 to 51.6 months), with 12 patients having progressed through pectus bar removal. One patient early in the series who underwent repair with MIRPE had a recurrence after bar removal owing to sites of malunion unrecognized at the initial repair with MIRPE. She subsequently underwent a hybrid procedure with excision of the scar tissue, bone grafting, and sternal plating. No hybrid patients have had major recurrences, but various revision procedures were performed in 4 patients (3 hybrid PE and 1 ATD). These procedures included removal of the titanium plate and revision with methyl methacrylate (1 patient), placement of a third support bar for continued lower chest wall PE (1 patient), removal of titanium plating because of postoperative infection requiring surgical debridement and later reoperation for restabilization after resolution of infection (1 patient), and repair of recurrent hernia at the chest wall muscle attachments with additional plating of lower associated costocartilage (1 patient). Two patients additionally underwent outpatient cosmetic shaving of osteophytic cartilage growth during the follow-up period.

Comment

Surgical repair of recurrent PE after previous open repair is often complex and presents special challenges. Others have reported successful MIRPE after failed open repair; however, in our cohort, less than a third were correctable with MIRPE [3, 6, 8]. Those patients with malunion, floating sternum, or significant ossification and deformity, such as in ATD, were not candidates for MIRPE alone, and the hybrid procedure was a good option. Adequate anterior elevation of the chest was not possible in almost half of our patients because of rigidly ossified chest walls, and many of the patients had sites of malunion, pseudoarthrosis, or chest wall hernia that required open repair [2, 10, 13]. Osteotomies of the sternum, sternocostal junctions, and lateral ribs were necessary to correct the chest wall to the proper position. Once elevation of the chest wall was achieved, complete stabilization of the freed chest wall segments in the desired anatomic position was found to be an important element of the hybrid procedure. Titanium plating or FiberWire was useful to stabilize these segments and reattach the sternum to the accompanying cartilage or ribs. Stabilization with pectus support bars was also performed to maintain elevation of the chest in the correct position and was far more satisfactory than the anterior plating alone done before this series.

Significant mediastinal scarring and pleural adhesions were encountered in many of our revisions of prior open extrapleural procedures. This led to significant bleeding requiring conversion to open sternotomy in 1 patient. Positioning and draping to allow rapid emergent access to femoral vessels and availability of cardiopulmonary bypass are important for reoperative patients. The use of forced sternal elevation or subxiphoid dissection has been recommended by others to increase the safety of dissecting mediastinal adhesions, and the current algorithm incorporates this recommendation [1, 3, 6, 8, 12, 22–28]. Although most patients do well, significant complications may occur. In general, complications increased with increasing complexity of the revision, as did operative time. The less complex hybrid patients had fewer overall complications and a shorter hospitalization (mean, 7 days versus 10 days), but were still hospitalized significantly longer than the revision MIRPE patients (5 days). Patients with extensive deformities and dystrophy required the longest mean operating room times (MIRPE, 165 minutes; standard hybrid, 295 minutes; ATD, 397 minutes). Extensive education about the extent of the surgical procedure, potential complications, risks, recovery period, and final results are necessary to create realistic expectations for the patient. As many of our patients underwent additional procedures, the possibility of future operations should also be well understood by the patient. The long-term durability of these repairs is unknown.

Repair of recurrent PE after prior open pectus excavatum surgery can be difficult. No single technique was found to be adequate for all patients, and more than half of our patients required a hybrid approach combining open resection, plating, and thoracoscopically placed support bars for correction. With appropriate techniques, recurrence after open PE can be repaired with good results, but a moderate degree of complications must be expected.

References

1. Antonoff MB, Erickson AE, Hess DJ, Acton RD, Saltzman DA. When patients choose: comparison of Nuss, Ravitch, and Leonard procedures for primary repair of pectus excavatum. J Pediatr Surg 2009;44:1113–9.
2. Colombani PM. Recurrent chest wall anomalies. Semin Pediatr Surg 2003;12:94–9.
3. Croitoru DP, Kelly RE Jr, Goretsky MJ, Gustin T, Keever R, Nuss D. The minimally invasive Nuss technique for recurrent or failed pectus excavatum repair in 50 patients. J Pediatr Surg 2005;40:181–7.
4. Ellis DG, Snyder CL, Mann CM. The 're-do' chest wall deformity correction. J Pediatr Surg 1997;32:1267–71.
5. Fonkalsrud EW. 912 open pectus excavatum repairs: changing trends, lessons learned: one surgeon's experience. World J Surg 2009;33:180–90.
6. Guo L, Mei J, Ding F, et al. Modified Nuss procedure in the treatment of recurrent pectus excavatum after open repair. Interact Cardiovasc Thorac Surg 2013:17258–62.
7. Mansour KA, Thourani VH, Odessey EA, Durham MM, Miller JI Jr, Miller DL. Thirty-year experience with repair of pectus deformities in adults. Ann Thorac Surg 2003;76:391–5.
8. Redlinger RE Jr, Kelly RE Jr, Nuss D, Kuhn MA, Obermeyer RJ, Goretsky MJ. One hundred patients with recurrent pectus excavatum repaired via the minimally invasive Nuss technique—effective in most regardless of initial operative approach. J Pediatr Surg 2011;46:1177–81.
9. De Ugarte DA, Choi E, Fonkalsrud EW. Repair of recurrent pectus deformities. Am Surg 2002;68:1075–9.
10. Jaroszewski D, Johnson K, Lackey J, McMahon L, Notrica D. Complex repair of pectus excavatum recurrence and massive chest wall defect and lung herniation after prior open repair. Ann Thorac Surg 2013;96:e29–31.
11. Jaroszewski DE, Notrica DM, McMahon LE, et al. Operative management of acquired thoracic dystrophy in adults after open pectus excavatum repair. Ann Thorac Surg 2014;97:1764–70.
12. Liu JF, Zhu SH, Xu B. Early results of 18 adults, following a modified Nuss operation for recurrent pectus excavatum. Eur J Cardiothorac Surg 2013;43:279–82.
13. Schulz-Drost S, Syed J, Besendoerfer M, et al. Elastic stable chest repair as a means of stabilizing the anterior chest wall in recurrent pectus excavatum with sternocostal pseudarthrosis: an innovative fixation device. Thorac Cardiovasc Surg 2014; Epub ahead of print.
14. Luu TD, Kogon BE, Force SD, Mansour KA, Miller DL. Surgery for recurrent pectus deformities. Ann Thorac Surg 2009;88:1627–31.
15. Aronson DC, Bosgraaf RP, van der Horst C, Ekkelkamp S. Nuss procedure: pediatric surgical solution for adults with pectus excavatum. World J Surg 2007;31:26–30.
16. Renz J, Reyes C. Repair of a floating sternum with autologous rib grafts and polylactide bioabsorbable struts in an 18-year-old male. J Pediatr Surg 2012;47:e27–30.
17. Prabhakaran K, Paidas CN, Haller JA, Pegoli W, Colombani PM. Management of a floating sternum after repair of pectus excavatum. J Pediatr Surg 2001;36:159–64.
18. Miller KA, Ostlie DJ, Wade K, et al. Minimally invasive bar repair for 'redo' correction of pectus excavatum. J Pediatr Surg 2002;37:1090–2.
19. Wang L, Zhong H, Zhang FX, Mei J, Li GQ, Xiao HB. Minimally invasive Nuss technique allows for repair of recurrent pectus excavatum following the Ravitch procedure: report of 12 cases. Surg Today 2011;41:1156–60.
20. Haller JA Jr, Colombani PM, Humphries CT, Azizkhan RG, Loughlin GM. Chest wall constriction after too extensive and too early operations for pectus excavatum. Ann Thorac Surg 1996;61:1618–25.
21. McMahon LE, Johnson KN, Jaroszewski DE, et al. Experience with FiberWire for pectus bar attachment. J Pediatr Surg 2014;49:1259–63.
22. Jaroszewski DE, Johnson K, McMahon L, Notrica D. Sternal elevation before passing bars: a technique for improving visualization and facilitating minimally invasive pectus excavatum repair in adult patients. J Thorac Cardiovasc Surg 2014;147:1093–5.
23. Ma IT, Rebecca AM, Notrica DM, McMahon LE, Jaroszewski DE. Pectus excavatum in adult women: repair and the impact of prior or concurrent breast augmentation. Plast Reconstr Surg 2015;135:303e-12.
24. Johnson WR, Fedor D, Singhal S. A novel approach to eliminate cardiac perforation in the Nuss procedure. Ann Thorac Surg 2013;95:1109–11.
25. Takagi S, Oyama T, Tomokazu N, Kinoshita K, Makino T, Ohjimi H. A new sternum elevator reduces severe complications during minimally invasive repair of the pectus excavatum. Pediatr Surg Int 2012;28:623–6.
26. Ohno K, Morotomi Y, Ueda M, et al. Comparison of the Nuss procedure for pectus excavatum by age and uncommon complications. Osaka City Med J 2003;49:71–6.
27. Yoon YS, Kim HK, Choi YS, Kim K, Shim YM, Kim J. A modified Nuss procedure for late adolescent and adult pectus excavatum. World J Surg 2010;34:1475–80.
28. Park HJ, Jeong JY, Jo WM, et al. Minimally invasive repair of pectus excavatum: a novel morphology-tailored, patient-specific approach. J Thorac Cardiovasc Surg 2010;139:379–86.

INVITED COMMENTARY

Repair of pectus excavatum is often associated with good and long-lasting results in terms of cosmetic appearance, physiology, psychological well-being, and quality of life. This is true whether performed via a traditional open approach (usually the modified Ravitch procedure) or a minimally invasive repair of pectus excavatum (MIRPE). However, the excavatum deformity will reoccur in a significant minority of patients. This varies in the reported literature from 2% to 20%, although, as Johnson and colleagues [1] note in this article for *The Annals of Thoracic Surgery*, the true incidence may well be higher.

Published by Elsevier

0003-4975/$36.00
http://dx.doi.org/10.1016/j.athoracsur.2015.04.004