Success of Minimally Invasive Pectus Excavatum Procedures (Modified Nuss) in Adult Patients (≥30 Years)

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Background. **Minimally invasive repair of pectus excavatum (MIRPE) has become standard for pediatric and young adult patients, but its use for older adults is controversial.**

Methods. **We retrospectively reviewed electronic medical records of adults (≥18 years of age) who underwent MIRPE from January 1, 2010, through April 30, 2015, and collected demographic data, operative details, and information about outcomes. Cardiac function was measured before and after repair by intraoperative transesophageal echocardiography. We divided patients by age: 18 to 29 years of age and 30 years of age and older.**

Results. **Of 361 patients, 207 were 30 or older (mean, 40 years; range, 30 to 72 years; 71.5% men). Of the older patients, 151 had primary repairs. MIRPE was successfully used in 88.7% of patients older than 30 years of age versus 96.5% of those 18 to 29 years of age. For patients 30 years of age and older, open-cartilage resection, sternal osteotomy, or both was more common with increasing age (mean, 47.8 years versus 39.5 years; $p = 0.0003$) and higher mean Haller index (7.7 versus 5.5; $p = 0.0254$). Mean operative time for MIRPE was significantly longer for older patients (≥30 years of age) compared with younger adults (121 [60 to 224] minutes versus 111 [62 to 178] minutes; $p = 0.0154$). Right ventricular output increased 65.2% after repair in older adults. Although greater, the frequency of bar rotation requiring reoperation was not significantly increased in the older patients ($p = 0.74$).**

Conclusions. **The majority of adult patients with PE can have successful repair with modified MIRPE. The use of cartilage or sternal osteotomy, or both, increased with patient age and defect severity.**

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Pectus excavatum (PE) is a posterior depression of the sternum and adjacent costal cartilages accounting for more than 90% of congenital chest wall deformities [1]. The cardiopulmonary consequences have been debated; however, most recent publications support repair of PE in patients with substantial symptoms [2–6]. Symptoms may worsen as a patient ages but resolve after the defect is repaired [4, 6–8]. With increased Internet-based social media and information sources, symptomatic adult patients with PE are learning of options for repair and seeking out surgeons for evaluation and potential correction of the defect.

Minimally invasive repair of pectus excavatum (MIRPE), or the modified Nuss, has become standard of care for surgical repair of PE in children [9, 10]. Initial attempts with MIRPE for adults resulted in higher complication rates, causing some surgeons to recommend limiting the procedure to pediatric and younger adults [11, 12]. With age, the chest wall becomes more rigid, which makes elevating the sternum and supporting the repair with substernal bars more complicated [13, 14]. To determine whether our data supported efficacy in older patients, we reviewed our MIRPE experience in adults and compared results for patients 18 to 29 years of age and 30 years of age and older.

Material and Methods

The Mayo Clinic Institutional Review Board approved this retrospective study, which included adult patients (18 years of age and older) who underwent PE repair from January 1, 2010, to April 30, 2015, with follow-up through December 31, 2015. Electronic medical records of 361 patients were reviewed to obtain data from the

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Table 1. Technique Modifications for Minimally Invasive Repair of Pectus Excavatum in Adults

Use forced sternal elevation to reduce the defect before dissection and bar placement.
Place multiple pectus support bars to balance the defect.
Use shorter pectus support bars without stabilizers.
Reinforce interspaces with FiberWire when intercostal muscle stripping is a risk.
Use FiberWire for multipoint fixation bilaterally.

preoperative evaluation, hospital course, and follow-up period. Only cases of primary repair were analyzed because of the complexity and heterogeneous nature of revisions. Patients with previous sternotomy were also excluded. Our patients were separated into cohorts by age (18 to 29 years of age and ≥30 years of age) for further evaluation and comparison.

Patient Evaluations

All adult patients underwent evaluations, including a physical examination, echocardiography, cardiopulmonary exercise testing (CPET), electrocardiography, and axial chest imaging (computerized tomography or magnetic resonance imaging). When available, expiratory imaging views were used to calculate the maximum Haller index and correction and compression indexes. Haller index was calculated by dividing the maximum internal chest width by the distance between the posterior sternum and anterior vertebral body [15]. Correction index was calculated by measuring the distance between the expected position of the corrected sternum and anterior aspect of the vertebra on imaging. This number was subtracted from the distance to the sternum at the site of deepest depression, divided by the first measurement, and then multiplied by 100 to find the percentage of potential correction [16]. Cardiac compression index was calculated by dividing the transverse cardiac diameter by the minimum anteroposterior cardiac diameter [17]. When the following criteria were met, patients were considered for surgical correction: Haller index of 3.2 or greater, correction index of 20% or greater, cardiac compression, cardiopulmonary deficits, substantial or progressing cardiopulmonary symptoms, and psychosocial effects [4].

Statistical Analyses

Prism 5.0 (GraphPad Software, Inc, San Diego, CA) was used for statistical analysis. All values were given as mean ± SD or mean (range). Unpaired, 2-tailed Student *t* tests were used to compare the 2 groups in the subgroup analysis, and paired, 2-tailed *t* tests were used for preoperative and postoperative comparisons. Complication frequency between different subgroups was analyzed by Ficher exact test and expressed as an odds ratio with 95% confidence interval; p values less than 0.05 were considered statistically significant.

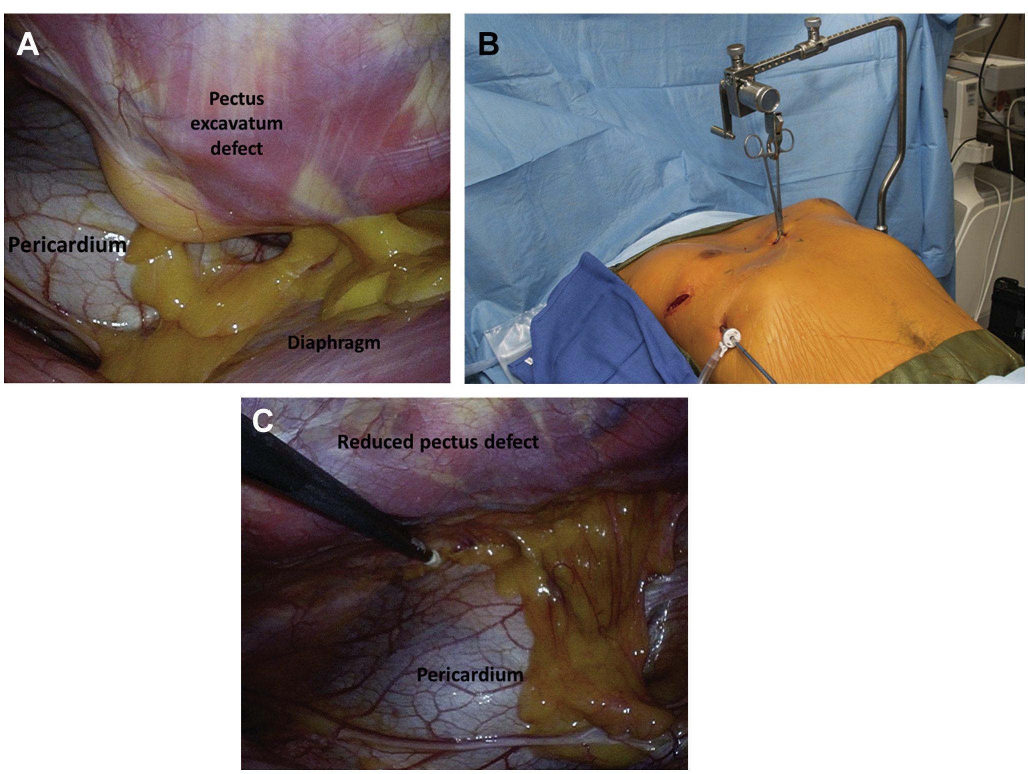


Fig 1. (A) Thoracoscopic view of the mediastinum showing a severe defect with cardiac compression. (B) Forced sternal elevation was performed with a sternal bone clamp attached to a bedside Rultract retractor. (C) Thoracoscopic view of the mediastinum and excavatum defect after sternal elevation.

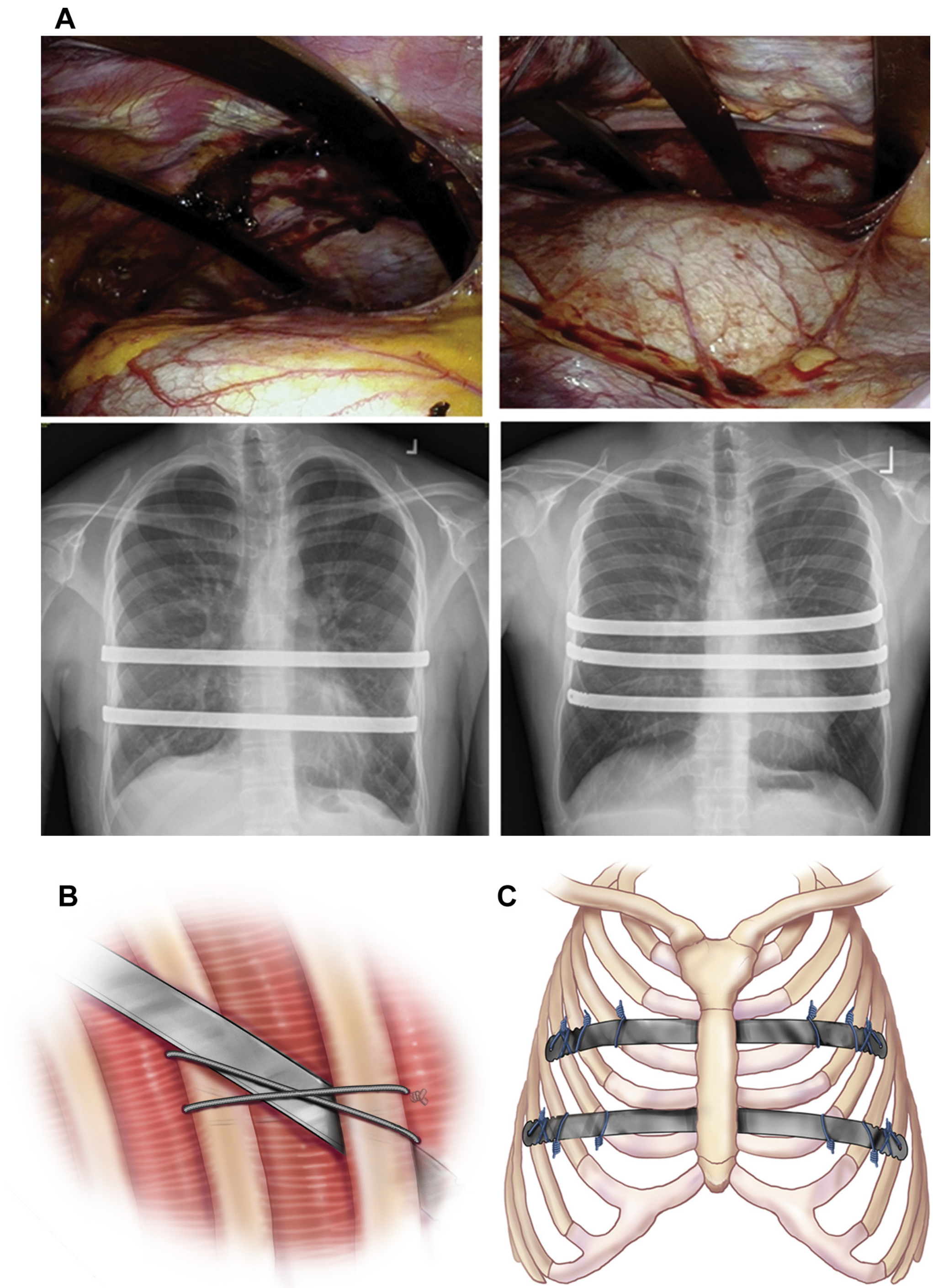


Fig 2. (A) View of 2 (left) and 3 (right) support bars shown by thoracoscopy and radiographs. (B) Figure-of-eight FiberWire reinforcement incorporates the rib above and below the interspace with the bar. (C) Bars fixed bilaterally and circumferentially around the rib with FiberWire. (Panels B and C used with permission of Mayo Foundation for Medical Education and Research.)

Surgical Procedure

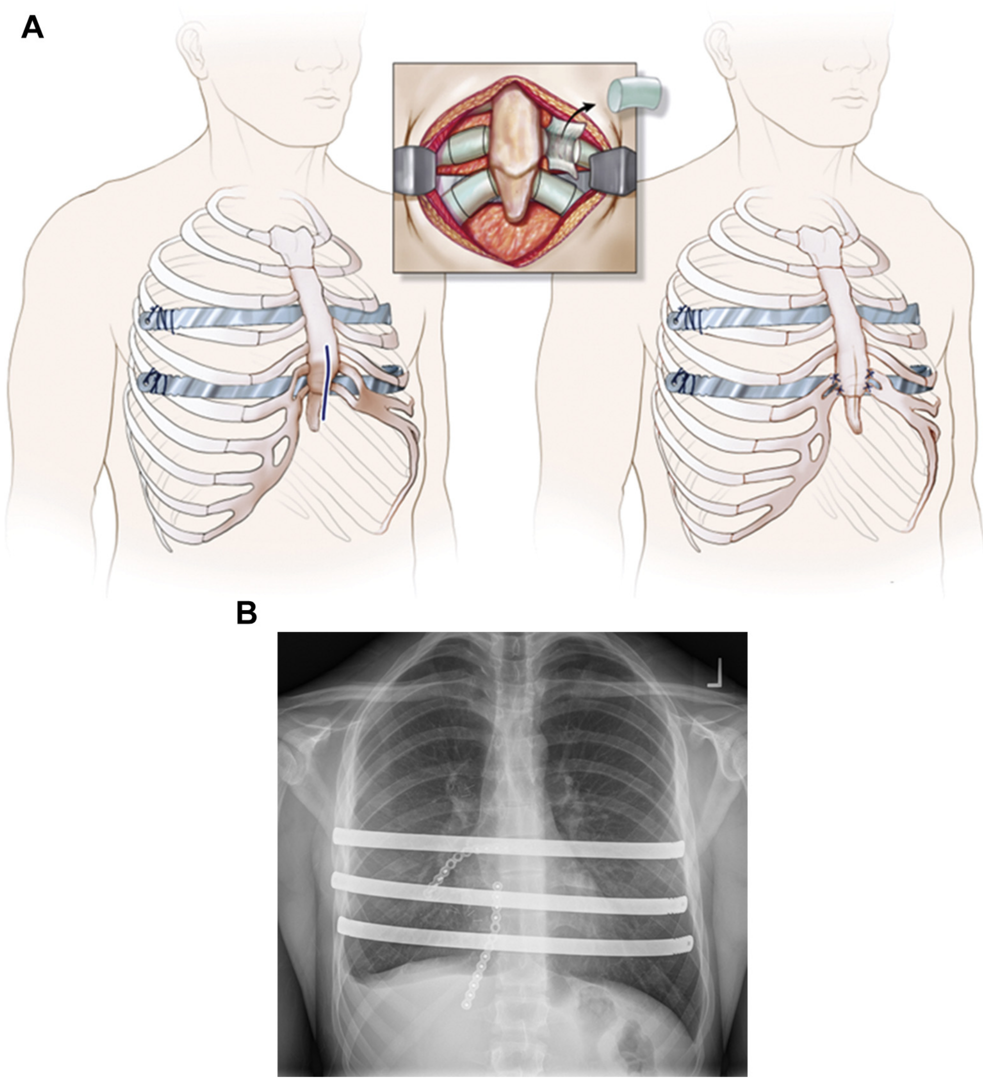
A MIRPE with technique modifications (Table 1) was attempted in all patients. Conversion to open hybrid resection was done only when the anterior chest deformity could not be fully elevated.

MIRPE Technique

The patient was positioned supine, with longitudinal gel rolls placed parallel to the spine and arms tucked at sides. Patients received preoperative antibiotic prophylaxis with intravenous cefazolin. A different medication was substituted for patients allergic to cefazolin. A double-lumen endotracheal tube was placed after general anesthesia induction. A transesophageal echocardiographic probe was placed to evaluate cardiac compression, function, and anatomy both preoperatively and postoperatively.

Bilateral, 3-cm incisions were made at the pectoral borders. Submuscular pockets were developed, and a

Fig 3. (A) Hybrid approach for excavatum repair. (B) Chest radiograph with 3 pectus support bars and anterior fixation plates. (Panel A used with permission of Mayo Foundation for Medical Education and Research.)



thoracoscopic port placed through the right incision. After carbon dioxide insufflation was begun, a second, a 5-mm port was placed for the camera on the right side, superior to the diaphragm. Forced sternal elevation was attempted, and if successful, MIRPE was done. At the center of the defect, a bone clamp (Lewin Perforating Forceps [V. Mueller NL6960], CareFusion, Inc, San Diego, CA) was placed into the anterior table of the sternum and attached to a Rultract retractor (Rultract Inc, Cleveland, OH) on the left side; the sternum was then elevated (Fig 1) [18].

The Lorenz dissector (Zimmer Biomet, Jacksonville, FL) was introduced into the interspace at the superior aspect of the defect through the right interspace and brought out through the contralateral interspace. A #5 FiberWire (Arthrex, Inc, Naples, FL) was attached to the dissector end and used as a guide for bar placement. Bars were custom bent and sized to extend 2 to 3 cm beyond the anterior axillary line. A second bar was placed 1 or 2 interspaces below the superior bar. If an inferior residual defect persisted, a third bar was placed (Fig 2A). Bars were rotated into place with the sternum still elevated to minimize intercostal rotational forces. If lateral stripping of the intercostal muscle occurred in the interspace of the bar, figure-of-eight FiberWire, incorporating the rib above and below, was used to reinforce the interspace and prevent later bar displacement (Fig 2B). FiberWire was used for bilateral circumferential fixation of the bars [19] in at least 3 sites, with additional medial fixation positioned closer to the rotational fulcrum at the bar's entrance into the chest (Fig 2C).

Technique for Failure to Elevate the Sternum

If the defect failed to elevate with forced sternal elevation, a hybrid approach was used. A limited midline incision was made over the affected sternum. The pectoral and rectus muscles were elevated, and a limited cartilage resection was made to release fixed sites until the defect was elevated. Sternal osteotomy was performed only if elevation was unable to be achieved otherwise

(Fig 3A) [20, 21]. The support bars were then placed and secured thoracoscopically as described previously for MIRPE [19]. Approximation and stabilization of resected cartilage to the sternum and sternal osteotomy sites were done by using FiberWire or titanium plating (Fig 3B).

Postoperative Care

Pain was controlled for all patients by our protocol, which was initiated in 2011 (Fig 4). Local anesthetic delivery was provided by thoracic epidural or pain catheters. When the procedure was completed, the surgeon placed 7.5-inch soaker catheters (PM050-A, On-Q, Halyard Health, Inc, Irvine, CA) anterior along the ribs, using a disposable, 17-gauge, 10-inch tunneling system (Model T17X10, On-Q, Halyard Health, Inc) (Fig 5). The catheters were primed and attached to a 750-mL reservoir. Variable rate controllers (Select-A-Flow, Halyard Health, Inc) were locked at a rate of 7 mL/h, infusing ropivacaine, 0.2%. The reservoir was refilled at 48 h for 5 days maximum. Patients were discharged with the On-Q in place unless removal was preferred. Patients who were medically stable were discharged home with oral pain medications if they did not have significant cognitive or respiratory adverse effects and had a pain score of 4 or less on oral pain medications for 24 h.

Results

During the study period, 361 adult patients (≥18 years of age) underwent PE repair; 207 (57.3%) were at least

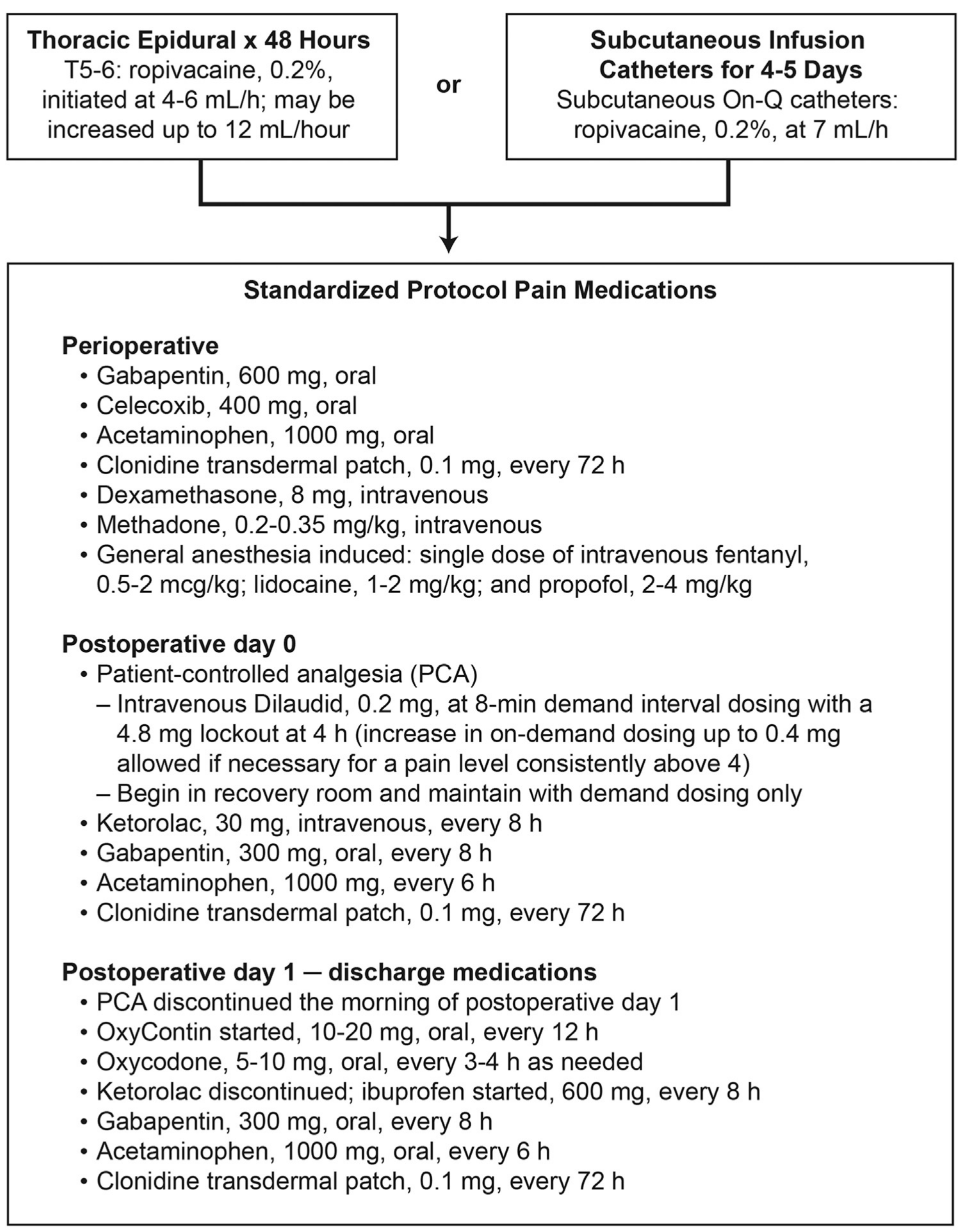


Fig 4. Algorithm for pain management after pectus repair.

Fig 5. On-Q catheters tunneled lateral to surgical site.

30 years of age. Of the total, 95 patients who had revisions were excluded from analysis (18 to 29 years of age: 39; ≥30 years of age: 56). Therefore, 266 patients with primary repairs were entered in the study (18 to 29 years of age: 115 [43.2%]; ≥30 years of age: 151 [56.8%]). Demographic characteristics of the 2 groups (18 to 29 years of age and ≥30 years of age) are compared in Table 2.

Of the 266 patients, 96.5% of those 18 to 29 years of age and 88.7% of those 30 years of age or older had successful PE corrections with MIRPE (Table 3). We then compared hybrid open procedures and MIRPE in a subset of the 30 years of age and over cohort. We found that open-cartilage resection, sternal osteotomy, or both were used more often for older patients requiring open procedures (age, 47.8 ± 13.1 years of age versus 39.5 ± 7.8 years of age; $p = 0.0003$) with higher mean Haller index (7.7 ± 5.6 versus 5.5 ± 3.2; $p = 0.0254$) and higher mean correction indexes (57.9% ± 18.8% versus 42.9% ± 15.6%; $p = 0.047$).

All patients underwent transesophageal echocardiography; however, only 101 patients older than 30 had complete preoperative and postoperative images adequate for review [22]. Right-sided heart dimensions (mean ± SD) were significantly improved after PE repair: right atrial size (3.4 ± 0.8 cm versus 4.0 ± 0.6 cm; $p < 0.0001$), end-systolic dimensions of the tricuspid annulus (2.6 ± 0.5 cm versus 2.8 ± 0.6 cm; $p = 0.0002$), end-diastolic dimensions of the right ventricular outflow tract (2.3 ± 0.4 cm versus 2.4 ± 0.4 cm; $p = 0.0002$), and systolic dimensions (1.6 ± 0.4 cm versus 1.8 ± 0.6 cm; $p = 0.0155$). Right ventricular output increased by 65.2% after repair (3.2 ± 1.0 L/min to 5.3 ± 1.5 L/min; $p = 0.0015$) (Fig 6).

Pneumonia, urinary tract infections, ileus, and hospital readmissions were significantly higher in the 30 years of age and older cohort (Table 3). Nine of these patients had to be readmitted within 30 days of discharge (pneumothorax, 1 patient; wound infection, 2 patients; ileus/nausea/vomiting, 1 patient; pleural effusion, 2 patients; and uncontrolled pain, 3 patients). A greater frequency of bar rotation occurred in the older patients, but it did not reach statistical significance (6.6% versus 1.7%; odds ratio, 4.0; 95% confidence interval, 0.86 to 18.67; $p = 0.07$). Hospital stay continued to decrease throughout the period reviewed but was significantly different between groups only for MIRPE between 2010 and 2012 ($p = 0.0009$).

Patients 30 and older in the MIRPE cohort were followed up for a mean (range) of 843.2 days (range, 4 to

Table 2. Patient Characteristics

Characteristic	Primary Repair Cohort, 30–72 Years of Age (n = 151)	Primary Repair Cohort, 18–29 Years of Age (n = 115)
Age, years	40.4 (30–72)	23.7 (18–29)
Men	108 (71.5)	88 (76.5)
Haller index	5.8 (2.5–24.9)	5.6 (2.5–26.7)
Correction index (%)	44.3 (20.2–85.4)	39.3 (21.6–80.6)
Cardiac compression index (%)	3 (1.4–10.0)	2.7 (1.6–4.9)
Prior cosmetic implants	20 (13.2)	3 (2.6)
Symptoms		
Dyspnea on exertion	142 (94.0)	115 (100)
Chest pain/pressure	106 (70.2)	79 (68.7)
Palpitations	111 (73.5)	79 (68.7)
Gastric fullness or reflux symptoms	29 (19.2)	8 (7.0)
Anxiety	26 (17.2)	23 (20.0)
Depression	13 (8.6)	9 (7.8)
Asthma/cough	33 (21.9)	26 (22.6)
Difficulty keeping up with peers	122 (80.8)	106 (92.2)
Cardiac compression (by echocardiography or other imaging)	116 (76.8)	92 (80.0)
Abnormal CPET with $\dot{V}O_2$ evaluation	68/102 evaluated (66.7)	61/79 evaluated (77.2)

Values are mean (range), n (%), or n/n (%).

CPET = cardiopulmonary exercise testing; $\dot{V}O_2$ = oxygen consumption.

Table 3. Outcomes

Variable	Primary Repair Cohort, 30–72 Years of Age (n = 151)	Primary Repair Cohort, 18–29 Years of Age (n = 115)	*p* Value
Successful MIRPE	134 (88.7)	111 (96.5)	0.0136
Use of forced sternal elevation by year			
2010–2011	4/38 (10.5)	0/14 (0)	
2012–2013	49/67 (73.1)	41/58 (70.7)	
2014–2015	46/46 (100)	42/43 (97.7)	
Support bars			
1	0 (0)	1 (0.9)	
2	83 (55.0)	65 (56.5)	
3	67 (44.4)	49 (42.6)	
4	1 (0.7)	0 (0)	
Implant removal, exchange, or placement	17 (11.3)	5 (4.3)	0.0457
Operative time, min			
MIRPE	121 (60–224)[b]	111 (62–178)[a]	0.0154
Hybrid procedure	231.1 (106–390)	247.5 (138–395)	0.8523
Local anesthetic pain control			
On-Q catheters	89 (58.9)	71 (61.7)	0.7049
Thoracic epidural catheter	62 (41.1)	44 (38.3)	
Estimated blood loss, mL			
MIRPE	57 (5–550)	47.6 (5–500)	0.1214
Hybrid procedure	359 (15–1000)	325 (100–800)	0.7091
Postoperative morbidity			
Bar rotation	10 (6.6)	2 (1.7)	0.0744
Infection	2 (1.3), both hybrid	1 (0.9)	1.0000
Pneumonia	6 (4.0), 1 hybrid	0 (0)	0.0381
Ileus/severe constipation	13 (8.6), 2 hybrid	1 (0.9)	0.0046
Readmission	9 (6.0), 3 hybrid	0 (0)	0.0059
Pleural effusion (and thoracentesis)	9 (6.0), 3 hybrid	3 (2.6)	0.2428
Pneumothorax (and chest tube)	1 (0.7)	1 (0.9)	1.0000
Pulmonary embolism	2 (1.3), 1 hybrid	0 (0)	0.5073
Urinary tract infection	6 (4.0), 1 hybrid	0 (0)	0.0381
Urinary retention (and catheterization)	13 (8.6), 1 hybrid	9 (7.8)	1.0000
Bleeding requiring transfusion	1 (0.7)	0 (0)	1.0000
Reoperation for bleeding	1 (0.7)[d]	2 (1.7)[c]	0.5801
Hospital length of stay by procedure and year, days			
MIRPE			
2010–2012	5.0 (2–11)	4.0 (2–6)	0.0009
2013–2015	3.3 (2–6)	3.1 (2–6)	0.2246
Hybrid			
2010–2012	5.6 (3–8)	5.0 (5–5)	N/A
2013–2015	5.6 (3–11)	6.5 (6–7)	0.7206

[a] Five minimally invasive repair of pectus excavatum (MIRPE) patients had time for implant or other cosmetic procedures excluded in operative times. [b] Fourteen patients who had MIRPE and 3 patients who had hybrid procedures had time for implant or other cosmetic procedures excluded in operative times. [c] Hemothorax evacuation, 1 patient; hematoma after breast augmentation, 1 patient. [d] Hematoma at site of implant removal.

Values are n (%), n/n (%), or mean (range).

N/A = not applicable.

2088 days), and 29 patients had bars removed (mean follow-up, 250.7 days; range, 1 to 687 days). No patients reported substantial symptom recurrence, although 1 patient reported some regression of the depression after bar removal.

Comment

As patients grow older, their PE symptoms may worsen [2, 4, 7, 23]. Kragten and colleagues [4] noted nearly half of their older patients' symptoms developed in their 30s to 40s. Decreased chest wall flexibility may be one reason for

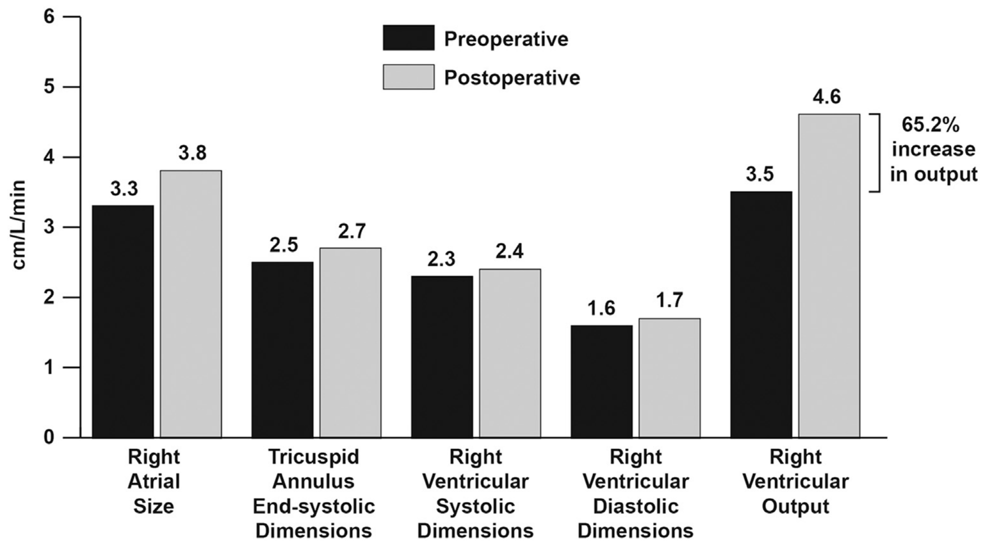


Fig 6. Right-sided heart dimensions measured by preoperative and postoperative transesophageal echocardiography (patients ≥30 years).

this symptom progression. When PE is corrected, symptoms may be substantially reduced or resolved [4, 6–8, 23]. Correlations between physiologic impact and symptoms in adults on CPET and by echocardiographic findings have been reported [3, 5, 6, 24–26]. Neviere and colleagues [3] also reported improved exercise function 1 year after operation in adults after PE repair. Significant increases in end-diastolic and right-sided heart

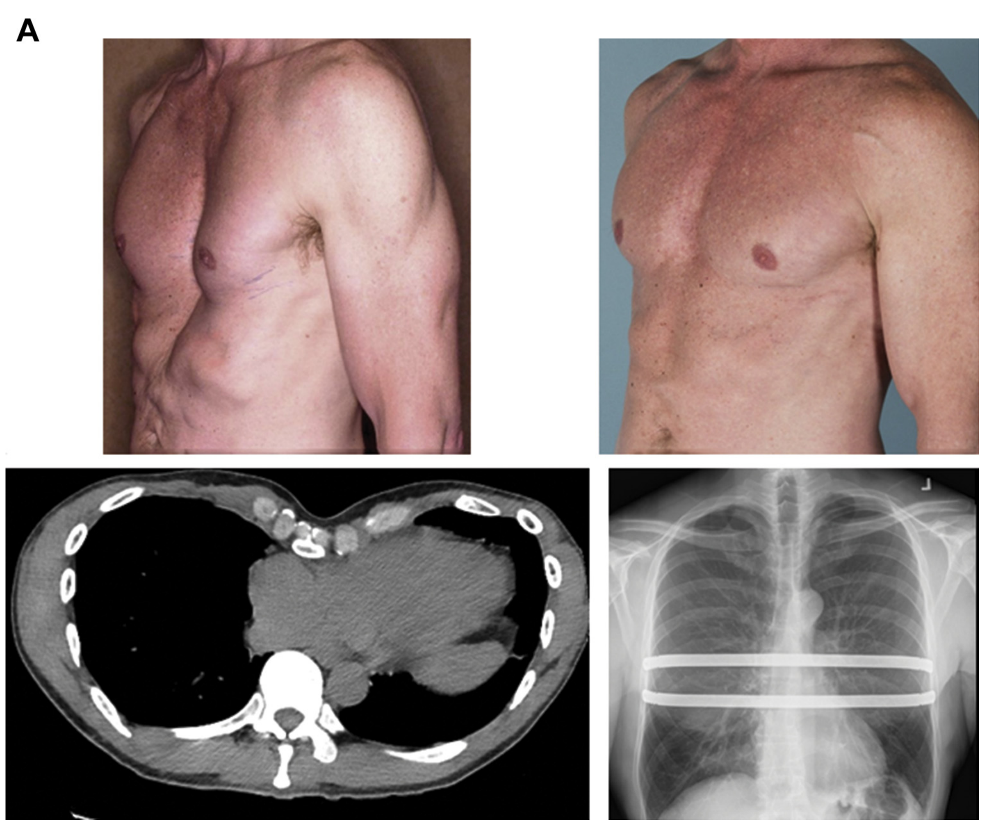
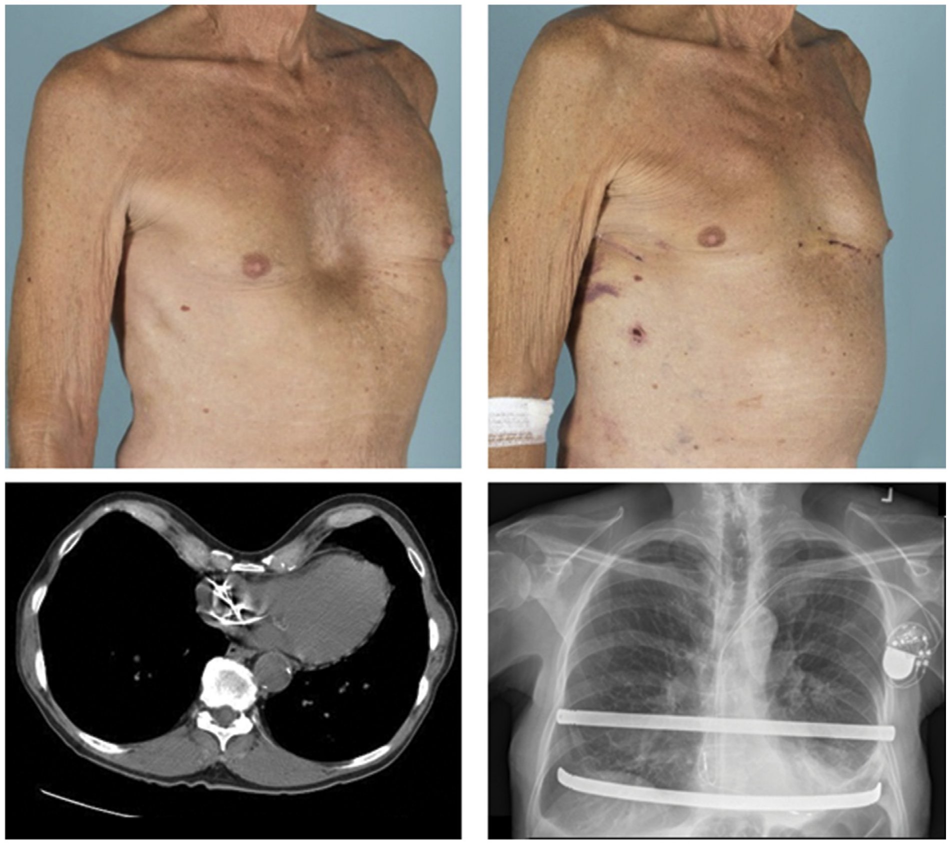


Fig 7. (A) A 58-year-old man before (left) and after (right) minimally invasive repair of pectus excavatum (MIRPE) with 2 bars (radiograph, bottom right). Computerized tomographic scan (bottom left) shows severe pectus excavatum (PE); Haller index, 5.7. (B) A 72-year-old man before (left) and after (right) MIRPE with 2 bars (radiograph, bottom right). Computerized tomographic scan (bottom left) shows severe PE; Haller index, 5.49. (C) A 38-year-old woman with prior breast implantation before (left) and after (right) MIRPE with 2 bars (radiograph, bottom right) and implant exchange. Computerized tomographic scan (bottom left) shows severe PE; Haller index 16.

B



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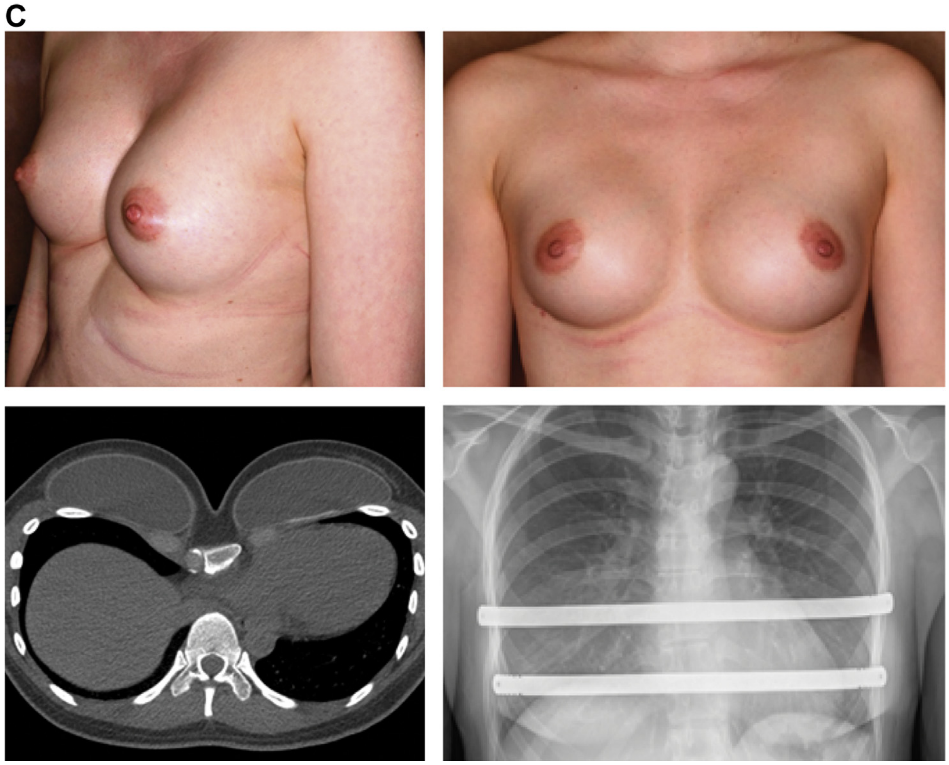

Fig 7. (Continued)

dimensions, biventricular ejection fraction, and right ventricular cardiac output have also been reported [22, 27, 28]. Our older patients (≥30 years) had a 65.2% intraoperative increase in right ventricular output on transesophageal echocardiography; however, only a small percentage have had postoperative CPET to document improved postoperative exercise function.

Many surgeons continue to advocate open procedures for adults undergoing PE repair despite reports of successful MIRPE in older patients [7, 29]. Their concerns include increased difficulty of repair and potential for higher postoperative pain and complication rates [30, 31]. We agree that repairs in older adults may be more complicated, and, therefore, technique modifications may be necessary for success [32–34]. In our experience, a higher percentage of older patients required osteotomy or cartilage resection (11.3% versus 3.5%); however, most defects were safely and successfully repaired with a modified MIRPE approach (Fig 7). Modifications, including use of forced sternal elevation, may help decrease the force required to insert and rotate bars [18]. This may lessen but not eliminate lateral stripping of the intercostal muscles of the more rigid chest wall. Using figure-of-eight FiberWire sutures to reinforce around the surrounding intercostal ribs provided bar stabilization and can prevent lateral-posterior migration when stripping occurs [19, 34]. Others have also reported using medial fixation and stabilizer placement to prevent stripping [33–35]. Multiple bars distribute pressure over a more rigid chest wall and may also help decrease the risk of bar rotation and malposition. In over 40% of our adult patients, 3 bars were required for complete correction. Others have reported decreased risk of migration and reoperation when multiple bars were inserted [18, 34–36]. In a study of PE repair in 44 late adolescent and adult patients, 11.5% of those with single-bar repairs required reoperation for bar rotation or incomplete correction compared with none of those who had a double-bar repair [37]. Although not found to be significant, bar migration did occur in more patients in our study's older group. This risk should be explained to patients in preoperative counseling about surgical alternatives.

For adults, support bars are recommended to remain for 3 years minimum. For children, the recommended interval has increased to 3 years, substantially decreasing recurrences [9]. For adults, recurrence rates as low as 2% to 5% have been reported for MIRPE; however, the numbers of patients and follow-up are limited [32, 35, 37–40]. Our study was limited by its retrospective nature. However, our purpose was to describe technique modifications that might allow PE repair in older adults and compare these results to those of our younger adults. Technique modifications allowed MIRPE to be used successfully in most of our older patients with few complications. Open osteotomy or chondroplasty may still be required to achieve repair in some adult patients.

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