Revision of Prior Failed/Recurrent Pectus Excavatum Surgery

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Abstract

Recurrence of pectus excavatum deformities occurs after both open and MIRPE. Recurrence risks are also based on multiple factors and differ based on the initial repair procedure. Identifying the contributing factors to a previous procedure's failure is critical to proper repair and prevention of another recurrence. Each case must be taken on an individual basis and is contingent on the patient's anatomy and previous repair technique. A combination of surgical techniques may be necessary in to successful repair some patients.

Keywords

Pectus Excavatum • Ravitch • Nuss • Complications • Recurrence • Failure • Revision surgery

Background

Surgical repair of pectus excavatum (PE) has evolved significantly over the past 50 years. There are a variety of techniques that have been successfully used on patients of all ages but the two most common methods used today include modifications of the open Ravitch approach and the minimally invasive repair (MIRPE) or "Nuss". Recurrence rates after repair of PE using both techniques have been reported in 2–37 % of patients [1–17]. No high-quality reports comparing long-term recurrences of MIRPE to open repair have been published. The cause of recurrence varies based on the technique of initial repair utilized. For patients presenting after failed or recurrent primary MIRPE repair; the placement, number of bars, bar migration, and too early of support removal can all be associated with failure (Figs. 15.1a, b and 15.2a, b) [2, 4, 12–14, 18–28]. Connective tissue disorders can complicate and increase recurrence risk in both previous Nuss and open PE repairs [1, 4, 29, 30]. Recurrence risks for the open repair are also

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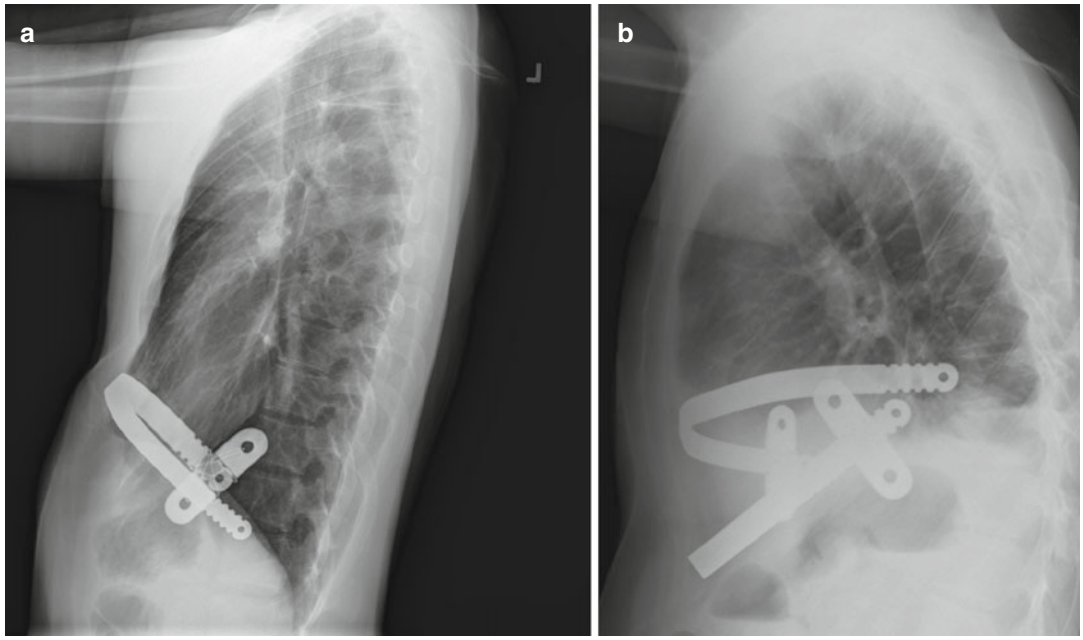

Fig. 15.1 (**a**, **b**) Failure of the Nuss procedure can be due to bar rotation or migration as is seen in these two patient's lateral chest roentgenogram (**a**) rotation of a long bar with single stabilizers is seen, (**b**) Rotation of the lower bar is seen on this patient with 2 support bars and stabilizers

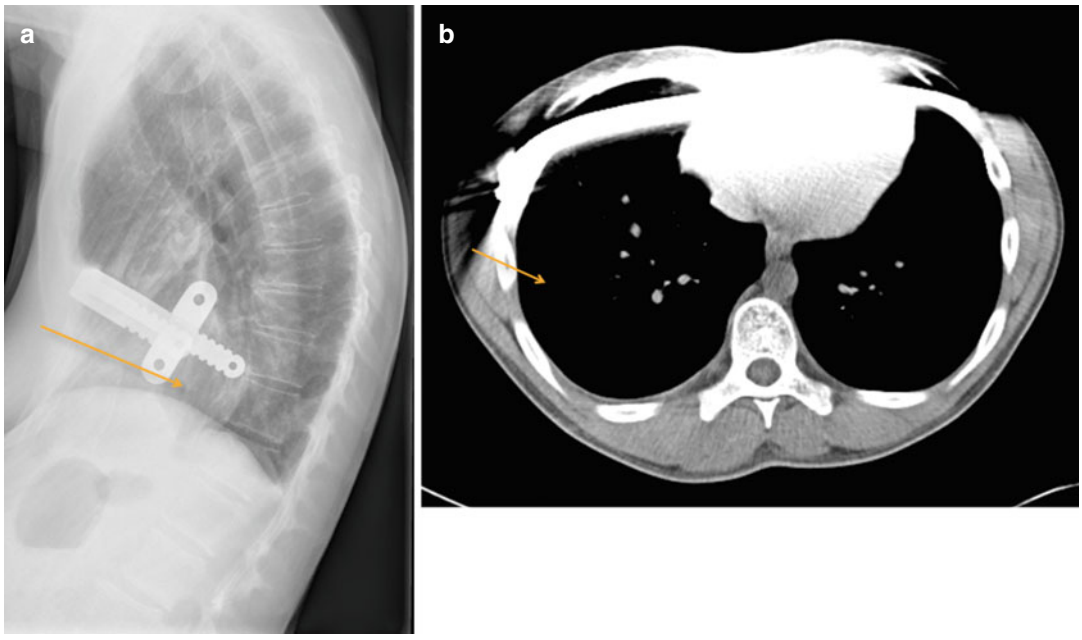

Fig. 15.2 Too lateral entrance of the support bars positions the support bars intrathoracic and fails to elevate the defect anteriorly. (**a**) posteriorly displaced bar is seen on in this patient's lateral chest roentgenogram. *Arrow* point to pectus excavatum defect still seen below the level of the bar. (**b**) computerized tomography shows intrathoracic portion of support bar with failure to support and elevate the pectus excavatum defect. *Arrow* points to the space between the chest wall and the bar

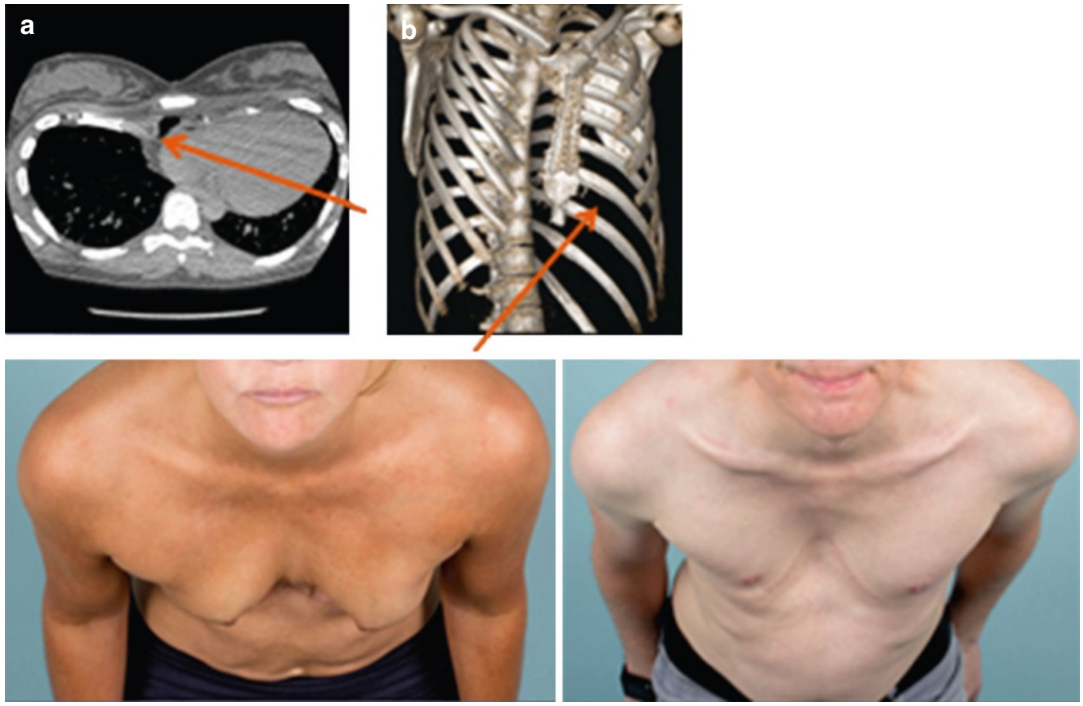

Fig. 15.3 Malunion and recurrence of pectus excavatum defect after previous Ravitch repair are seen in these patient's photographs, computerized tomography and 3-D reconstruction images (**a**) A 46 year-old female with significant recurrence after open Ravitch procedure. CT scan shows failed union between the rib (*thin arrow*) and Sternum (*thick arrow*) (**b**) A 44 year old male with significant recurrence after open Ravitch procedure. 3D reconstruction shows recurrence and failure of the chest wall to reconstitute

based on multiple factors which include incomplete previous repair, repair at a young age, dissection either too extensive or too little, early removal or lack of support structures, and incomplete healing of the chest wall with pseudoarthrosis and necrosis (Fig. 15.3a, b) [1, 3, 5, 8, 13–15, 16, 21, 31–34, 35, 36].

Regardless of which initial procedure was used, some patients will experience recurrence. There are only a few publications devoted exclusively to repair of recurrent pectus deformities, and most studies include children with only a few adults [1–5, 9, 11, 13, 14, 31, 37]. Several of these publications are reviewed in Table 15.1. Most of these reports describe experience with a single operative technique in the repair of recurrent pectus excavatum. The reports by Redlinger and Croitoru et al. advocated a modified Nuss technique for both open and Nuss recurrent PE [13, 14]. Multiple bars were required and they reported slightly higher complication and bar displacement rates with revision versus primary repairs. Others have advocated the use of a modified open Ravitch repair in all patients with recurrent PE, reporting excellent results in a small group of patients, with only a marginally longer length of stay compared to patients undergoing primary repair (6 days versus 5 days) [9]. Studies have shown that repairs in adults may be more difficult and have increased risks of complications due to increased rigidity of the chest wall [3, 7, 10, 18, 30, 31, 38–48]. Complex open repairs were required in many adult patients after prior open repair when compared to other studies [9, 32, 33]. Luu et al., reported on 13 recurrent patients in ages 16–54 years [9]. Eight of these were previous MIRPE and 5 had been a modified Ravitch repair. All of the failed MIRPE procedure patients in this series underwent a modified Ravitch repair for correction, while the recurrent open repair patients required complex reconstructions. Results are reported as good or excel-

Table 15.1 Publications for the surgical treatment of recurrent pectus excavatum

Author	# of patients	Median age at time of reoperation	Primary repair procedure (Nuss, open)	Operative technique secondary repair	Median operative time	Results reported	Length of follow-up (average)
Croitoru et al. [14]	50	16 years	Nuss 23 Open 27 Multiple 2	Minimally invasive Modified Nuss	140 min	8 % required revision surgery for bar displacement, 85 % report increased exercise tolerance post-op	NR
Liu et al. [31]	18	21 years	Nuss 1 Open 16 Other 1	Minimally invasive Modified Nuss	68.5 min	No bar displacement requiring reoperation, 14/18 (85 %) excellent result, 4/14 (15 %) good result	19 months
Miller et al. [11].	10	15 years		Minimally invasive Modified Nuss	70 min	Good or excellent results in all patients, no complications	23 months
Redlinger et al. [13].	100	17 years	Nuss 51 Open 45 Multiple 4	Minimally invasive Modified Nuss	NR	Bar displacement in 9 patients, 7 of which required reoperation, 2 intraoperative cardiac arrest	NR
Wang et al. [49].	12	15 years		Minimally invasive Modified Nuss	100 min	Bar displacement in 2 patients, no reoperation, excellent result in 66.7 %, good in 25 %, fair 8.3 %	10–38 months
Guo et al. [5].	28	15 years	Open 28	Minimally invasive Modified Nuss	86 min	Excellent results 64 %, Good 25 %, fair 11 %	24–72 months
Pison et al [64].				Minimally invasive Modified Nuss			
Luu et al. [9]	13	28 years	Nuss 8 Open 5	Nuss recurrences modified Ravitch Open recurrences required complex reconstruction not described	NR	1 patient returned to OR 2 years later for resection of protuberant costal cartilage, 10/13 excellent result, 2/13 good result	NR
Schulz-Drost et al. [34]		29 years	Open 7	Open revision with plating	205	High patient satisfaction results only	NR

lent in many patients undergoing reoperation [5, 9, 11, 31, 49]. Follow up is limited and the long-term durability of repairs unknown. Many publications do not report their length of follow up. Those studies that do provide a longer length of follow up have shown good efficacy in preventing further recurrence of PE during the follow-up periods [2, 5, 11, 31, 49].

Surgery for Recurrent Pectus Excavatum

In general, reoperative repair should avoid or repair the issues that contributed to the first surgical approach recurring. Assessment of why a patient's repair was unsuccessful or recurred is necessary for treating recurrence adequately. Both open and minimally invasive techniques have been described for repair of recurrent PE. Both approaches can offer advantages in the repair of recurrent defects, however, some recurrent defects may require an application of both open and minimally invasive repair techniques to achieve optimal outcomes. Regardless of the approach advocated, reports describing experience with repair of recurrent PE all mention the increased technical difficulties, higher complication rates and longer hospital stays [9, 11, 13, 14].

Recurrent Pectus Excavatum after MIRPE or Nuss Procedure

Recurrences following the Nuss repair are reported at a similar rate as that seen after Ravitch however many aspects of the presentation differ. Technical issues constitute a large proportion of the cases reported as "failed" versus "recurrent" in patients repaired with MIRPE. Some of the more common technical failures and causes reported for recurrent PE after Nuss procedure are listed in Table 15.2.

The majority of experienced centers reporting on revision of prior failed or recurrent MIRPE patients found that malpositioned or displaced bars were a large portion of the issue [2, 5, 13, 14, 31] (Fig. 15.4a–c). Bar displacement is the most common complication following Nuss repair, with displacement rates greater than 10 % in some studies [6–8, 12, 19, 23, 25–27, 42, 43, 50–54]. Adult patients have also been noted to have a greater incidence of bar rotation and complications [4, 5]. This can lead to recurrence of the pectus deformity as well as need for subsequent reoperation. There are a variety of different issues that can lead to bar rotation and migration. The majority of revisions reported on noted bars that were too long (Fig. 15.5) [13, 14]. These bars were replaced with bars that were 1–4 in. shorter on average. Bars that were placed too lateral or intercostal stripping and lateral displacement occurring after placement was another common technical issue noted (Fig. 15.6a, b). When lateral displacement occurs, the bar will fail to contact the sternum and support it anteriorly (Fig. 15.7). The entry and exit sites into the chest should not be too lateral or muscle stripping can occur [13, 14, 20, 26, 53]. Use of a different interspace was recommended should intercostal stripping and lateral displacement occur [13]. Figure of eight suture reinforcement of the ribs bordering the stripped intercostal space can also be performed. The utilization of forced sternal elevation may also help facilitate bar placement and rotation and minimize intercostal stripping [55].

Table 15.2 Frequent causes of failed or recurrent prior MIRPE or Nuss procedure

Rotation or displacement of bars
Bars too long
Bars placed too lateral
Intercostal Stripping
Disproportionate weight distribution of chest wall on number of bars
Failure of bars to remain secured to chest wall
Failure to lift with bar placement
Chest wall too stiff and non-compliant
Adequate number of bars not utilized for weight & compliance of chest wall
Adequate number of bars not utilized for length and depth of defect
Bars stripped lateral failing to support chest anteriorly
Premature removal of bars
Connective tissue disorders

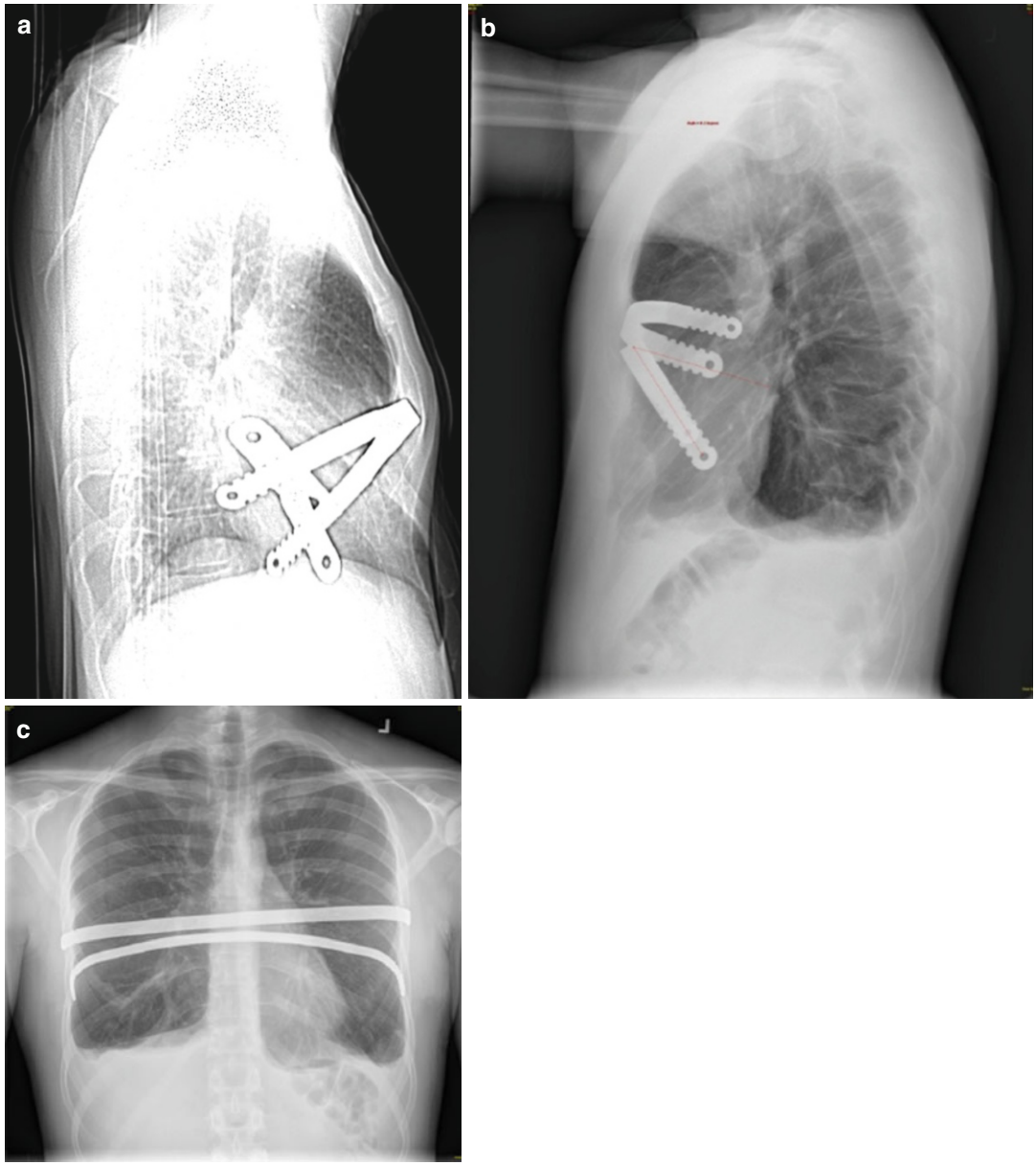

Fig. 15.4 (**a–c**) Lateral chest and A/P roentgenograms show bar rotation and migration in three patients after Nuss pectus excavatum repair

Adequate stability is also impacted by the number of bars and balance of the chest wall on support structures. For heavier, stiffer chests, several bars may be necessary to support the weight and elevate the defect. The pressure required to elevate the chest is significant and an inadequate number of bars to support the chest anterior can lead to lateral stripping of the intercostals and increased risk of bar rotation [22, 27, 55–58]. Recommendations as to what the adequate number of bars are varies [6, 18, 20, 25, 53, 59]. Initial reports of the Nuss procedure encompassed young patients with only one bar advocated however the majority recommend increased number of bars with more significant defects and advanced ages [53]. Older patients have also

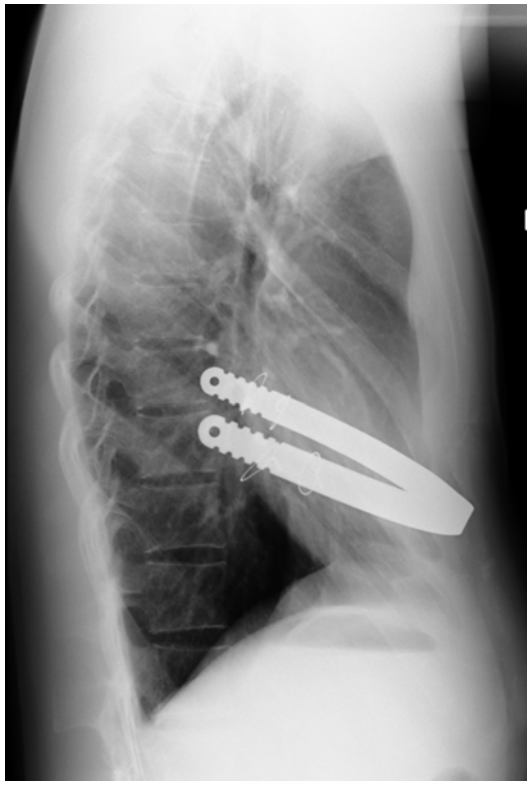

Fig. 15.5 Lateral roentgenogram of patient with recurrent pectus defect less than 1 month after Nuss repair and placement of single bar. Note a longer than recommended length of bar and curvature beyond the mid-axillary line with rotation and displacement

been reported by others to require more bars for PE repair and two or more bars may give better and more stable results [18, 25, 58, 60, 61]. For some patients presenting with reported recurrence, there may have been an incomplete repair of their defect following the initial Nuss with a portion of their defect remaining postsurgical due to an inadequate number of support bars (Fig. 15.8a–c) [3].

Recurrence has also been attributed to premature removal of the pectus bars before adequate remodeling has occurred and the chest wall secured into a corrected position. The optimal length of time recommended to leave support bars in place varies however, several experienced centers have increased their recommended time to 2–3 years [6, 7, 25, 40, 57, 62]. Patients with Marfan's and other connective tissue disorders have been shown to have a higher risk for recurrence and recommendations are for leaving the bars in place for up to 4 years [1, 4, 29].

A significant problem encountered after a failed Nuss can be extensive intrathoracic adhesions [5]. These can require several hours of extensive adhesiolysis before dissection across the chest and mediastinum is achieved for bar placement. Use of sternal elevation may be helpful and others have described a subxiphoid incision to manually elevate the sternum during dissection across the chest, especially with extensive adhesions [5, 9, 13, 14, 63, 64].

Recurrent Pectus Excavatum after Ravitch and Open Procedures

The original open procedure for PE repair was described and accredited to Ravitch in the 1940s [65, 66]. Modifications of this technique have been used successfully for several decades [2, 15, 42, 67–69]. The open repair involves resection of the deformed costal cartilage with or without sternal osteotomy. Recurrence risks are based on multiple factors as listed in Table 15.3. Once recurrence occurs, subsequent repair becomes more complex. The challenges encountered with re-operative repair can vary based on the extent of initial operative repair. There is limited literature published on repair of recurrent open PE, however, most reported higher complication rates, longer hospital stays, and higher rates of bar displacement when repaired with MIRPE [5, 13, 14].

Surgical repair of patients having undergone a previous Ravitch or other open PE repair technique may have unique problems when recurrence occurs. Repair can be quite challenging due to rigidity of the bony chest wall and scar tissue from the prior surgical intervention. Extensive calcification, ossification and fusion of the previously excised cartilage may prevent adequate elevation of the chest wall without reexcision [9, 32, 33, 35, 70]. Osteotomies of the sternum, sterno-costal junctions and more laterally along the ribs may be necessary to mobilize the anterior chest wall. Recurrences following open PE repair

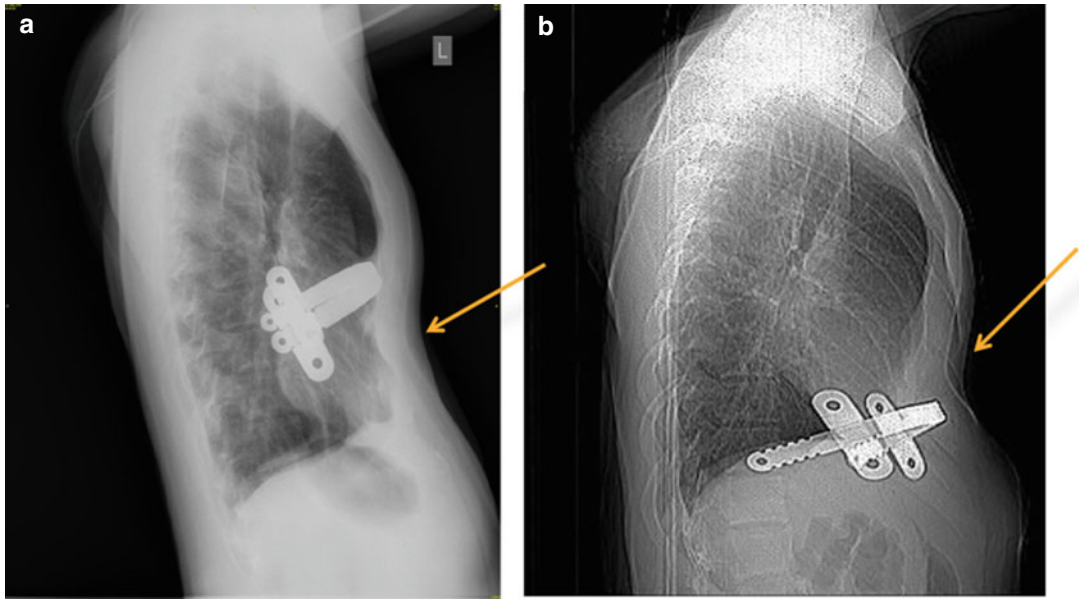

Fig. 15.6 (**a**, **b**) Lateral chest roentgenograms showing single pectus bar with failed elevation of the pectus excavatum defect secondary to lateral displacement (**a**) and intrathoracic migration (**b**). *Arrows* note pectus excavatum deformity still present despite support bar indwelling

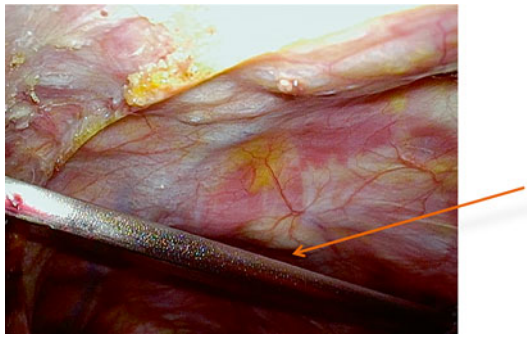

Fig. 15.7 Thoracoscopic view of intrathoracic pectus support bar which fails to contact the anterior chest wall due to lateral intercostal placement. *Arrow* notes space between chest wall and support bar

can also arise from osteonecrosis, malunion due to pseudomembranous attachments, instability and/or chest wall hernia (Fig. 15.9a, b) [1, 3, 4, 9, 17, 31, 33]. When non-union occurs bilaterally, this can also lead to an entity known as "floating sternum", which requires revision to reattach and stabilize the sternum (Fig. 15.10) [34, 36, 71].

Successful repair of areas of malunion, pseudo-arthrosis and sternal floating requires repeat open repair. Open repair and stabilization has also been recommended by other authors for these complicated recurrences [3, 9]. Rib/sternal reattachment and sites of repeated osteotomies prone to malunion or non-union can be approximated with titanium plating or Fiberwire™ (Arthrex, Inc, Naples, FL).

Rigidity of the chest wall following Ravitch is the main component that must be overcome to achieve an adequate repair. MIRPE is more difficult as a result, and bar displacement more likely. Additionally, a study by Redlinger et. al. also mentions findings of significant intrathoracic adhesions following Ravitch repair, despite this being considered an extra-pleural repair, making placement of pectus bars difficult [13]. The use of forced sternal elevation to move the sternum anterior has been reported to be helpful for safe dissection and repair with MIRPE [55, 57, 72–74].

Despite these challenges, MIRPE following previous open repair can be quite successful [5, 11, 14, 31]. Redlinger et al. reported on 100 patients they successfully repaired with the Nuss procedure after recurrences (45 prior open and 51 prior Nuss) [13]. Repair of patients with previous

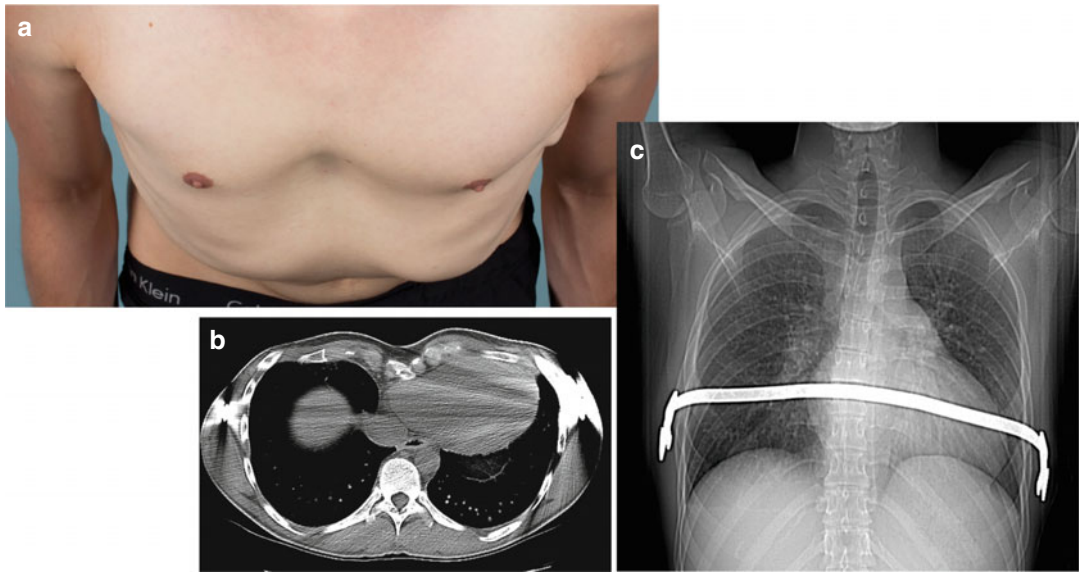

Fig. 15.8 (**a**–**c**) Photographs (**a**) and radiographic imaging (**b**, **c**) are shown of a 26 year-old male with pectus excavatum deformity 2 years after placement of single support bar with residual defect of Haller Index 4.6 and chronic postoperative pain. The single bar fails to elevate and support the defect inferiorly

Table 15.3 Frequent causes of failed or recurrent prior Ravitch/open procedures

Incomplete previous repair
Repair at too young of age
Dissection either too extensive or too little
Early removal or lack of support structures
Incomplete healing of the chest wall with pseudoarthrosis, "sternal floating and osteonecrosis"
Connective tissue disorders
Infection and seroma complications

Ravitch procedures required multiple bars. Opening the previous Ravitch incision for manual lifting of the sternum during the dissection under the pectus defect was felt to significantly improve the safety of the dissection and success of the procedure [13].

Rarely following Ravitch repair at too young and age, patients can have impairment of the normal chest wall growth, or acquired asphyxiating thoracic dystrophy, which was first described by Haller in 1996 [35]. Haller speculated that this "acquired Jeune's syndrome" was related to disruption of the normal growth centers of the affected ribs. These patients typically had repair of their defect at a very young age (<4 years), which had been common in the 1970s and 1980s. This is a complicated disorder with high risks for reconstruction to improve the chest defects presents. These patients required complex reconstructions of which discussion is beyond the context of this report and limited reports are published [21, 32, 35].

Indications for Surgical Revision Repair

Indications for repair of recurrent pectus excavatum are similar to those for primary repair and reviewed in Table 15.4 [1, 3–5, 9, 11, 14, 37, 64, 75–82]. Those patients with a recurrent, significant defect and those with symptomatology correlating with the return of their defect, including dyspnea, palpitations, and inability to keep up with their peers, all factor into the decision to repair a recurrent defect. Additionally, patients that have undergone previous open repair may have areas of non-union, chest wall hernias and other conditions that lead to chronic pain and chest wall instability [3, 33–35, 37, 71, 76].

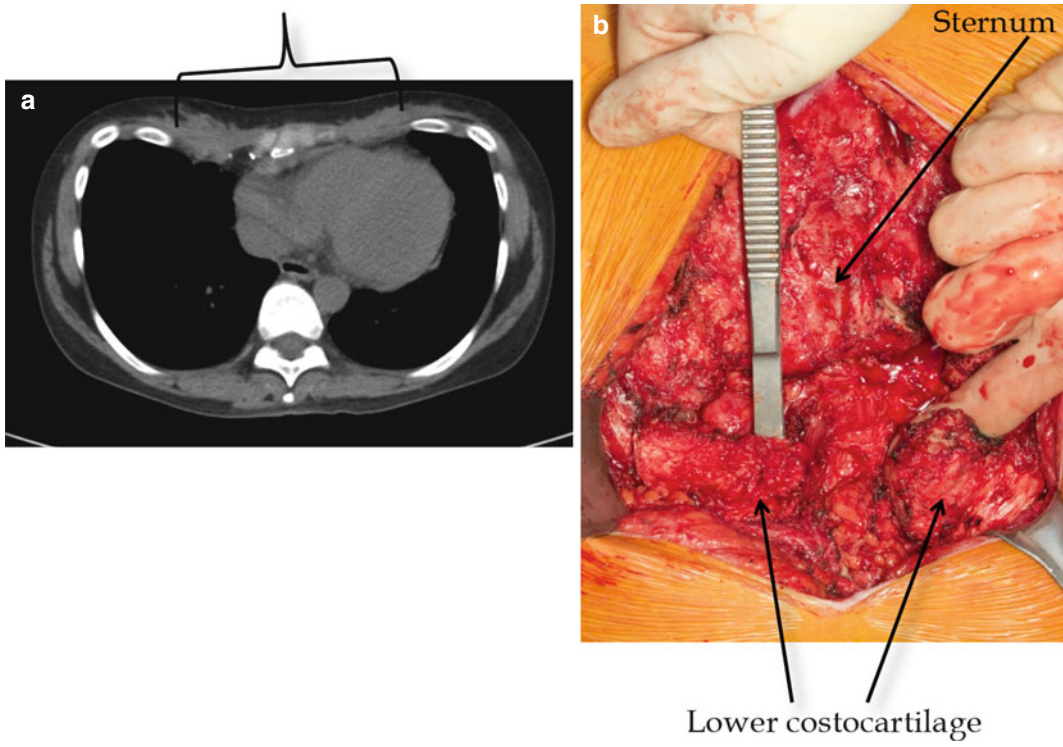

Fig. 15.9 (**a**, **b**) Computerized tomography (**a**) of the chest and intraoperative photograph (**b**) showing fibrous malunion and recurrence due to improper healing after prior Ravitch pectus repair. The instrument is place under the lower cartilage attachments which are completely separate from the sternum. *Arrows*

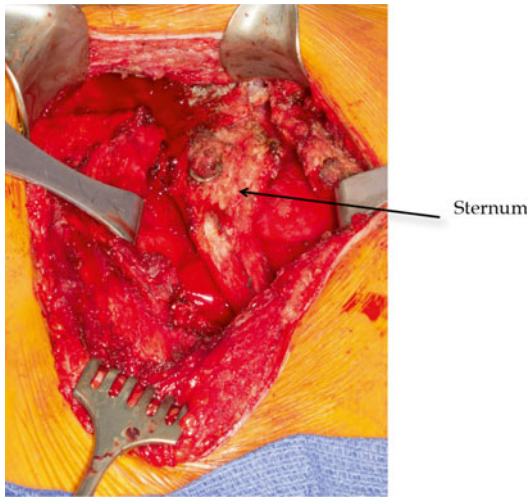

Fig. 15.10 Intraoperative photograph showing "sternal floating" after prior open Ravitch pectus repair with bilateral non-union of costocartilages and sternum

Resultant symptoms from this type of defect can be severe and may be an indication for surgery despite not meeting criteria based on the measurements of their defect. Reoperation should be individualized to the patient with great consideration given to the increased operative complexity and risk of complications. Extensive patient education about the surgical complications, recovery period, and final results are necessary to create realistic expectations for the patient.

Table 15.4 Indications for surgical revision of prior failed pectus excavatum

Haller Index greater than 3.25 or Significant Correction Index
Continued evidence for Cardiac Compression
Symptomatology correlating with return of defect
Non-union, pseudoarthrosis or sternal/chest wall instability

In general, we have approached all our revision cases from a stepwise evaluation including:

1. **Physical exam** to identify areas of pseudoarthrosis and malunion between the sternum and ribs, or serial instability of the costal joints

"floating sternum" [36, 71]. Assessment of compliance and residual flexibility of anterior chest wall.

2. **CT or MRI** studies of the chest are necessary to allow for measurements of the defect, but also for visualization of areas of malunion or non-union that are not appreciated on physical exam. Identification of chest wall hernia, irregular cartilage regeneration at the retrosternal level and incomplete reunion of previous resection sites can be performed [70, 81, 83–85].
3. Evaluation of prior operative notes, chest roentgenograms and films relative to patient's prior procedures.
4. Evaluation of physiologic abnormalities which may include echocardiogram, pulmonary functions and cardiopulmonary V02 and exercise parameters [7, 23, 75, 80, 81, 86–92].

For the majority of reoperative patients, we plan MIRPE utilizing forced elevation (Johnson, ATS publication pending) (Fig. 15.11a, b). shows an algorithm for our approach to revision patients. Open resection with osteotomy and partial modified revision Ravitch are performed when necessary if the chest wall will not elevate adequately. Patients with pseudoarthrosis or "floating sternum" are planned for a combined procedure with elevation of the chest wall and stabilization of sternocostal instability [36, 71]. Patients with acquired thoracic dystrophy require more complex open reconstructions [32, 35] Table 15.5 outlines the operative steps:

Procedure Detailed Description

All patients are administered intravenous antibiotic prophylaxis prior to initiation of procedure. General anesthesia with double-lumen intubation is performed. A transesophageal echocardiogram probe is placed and cardiac compression, function, and absence of pericardial effusion documented throughout the case. The patient is placed in supine position with arms secured at the sides. Two longitudinal 5-in. rolls are placed under the back parallel to the spine and the arms padded and tucked at the sides. Groins are left exposed and prepped into the surgical field should emergent access and cardiopulmonary bypass be necessary (Fig. 15.12). This positioning facilitates access to both anterior and lateral aspects of the chest wall for placing and affixing bars.

Single 3-cm incisions are made bilateral following the rib contour at the inferolateral pectoral borders. Incisions are positioned to allow access to the intercostal spaces adjacent to the defect. Submuscular pockets are developed utilizing electrocautery to elevate the pectoralis muscles off the chest wall along the anterior and lateral chest wall. Initially a 5 mm port is placed through the right incision and carbon dioxide insufflation to 5–8 mmHg pressure is utilized. A 5-mm flexible endoscope (Olympus 5-mm Endoeye Flex 5, Central Valley, PA) is placed and allows safe placement of a second 5 mm port inferiorly in the right chest for visualization of intrathoracic procedures. Careful takedown of intrathoracic adhesions is performed under direct visualization. No attempt to cross the mediastinum occurs until sternal elevation is achieved.

Elevation with the RulTract Retractor (Ruletract Inc., Cleveland, OH) is then attempted (Fig. 15.13) [55, 57].Two-mm incisions are placed on either side of the sternal defect and the perforating tips of a bone clamp (Lewin Spinal Perforating Forceps, V. Mueller NL6960; CareFusion, Inc, San Diego, CA) are inserted into the sternum. The clamp is then fully closed. The RuleTract Retractor is attached to the table at the level of the mid-sternum on the left side. The sternum is then attempted for elevation.

If Elevation Is Achieved, a Modified Nuss Will Be Performed for the Revision Case

Procedure for Modified Nuss for Revision

The first bar is positioned in the interspace at the superior aspect of the defect. A second bar is then placed 1–2 inner spaces below this one. If there is residual lower defect, a third bar will be placed (Fig. 15.14a, b). Bars are sized and shaped to best correct the patient's defect. We use shorter bar lengths and try to minimize the lateral extension of the bar around the chest. Bars are custom bent

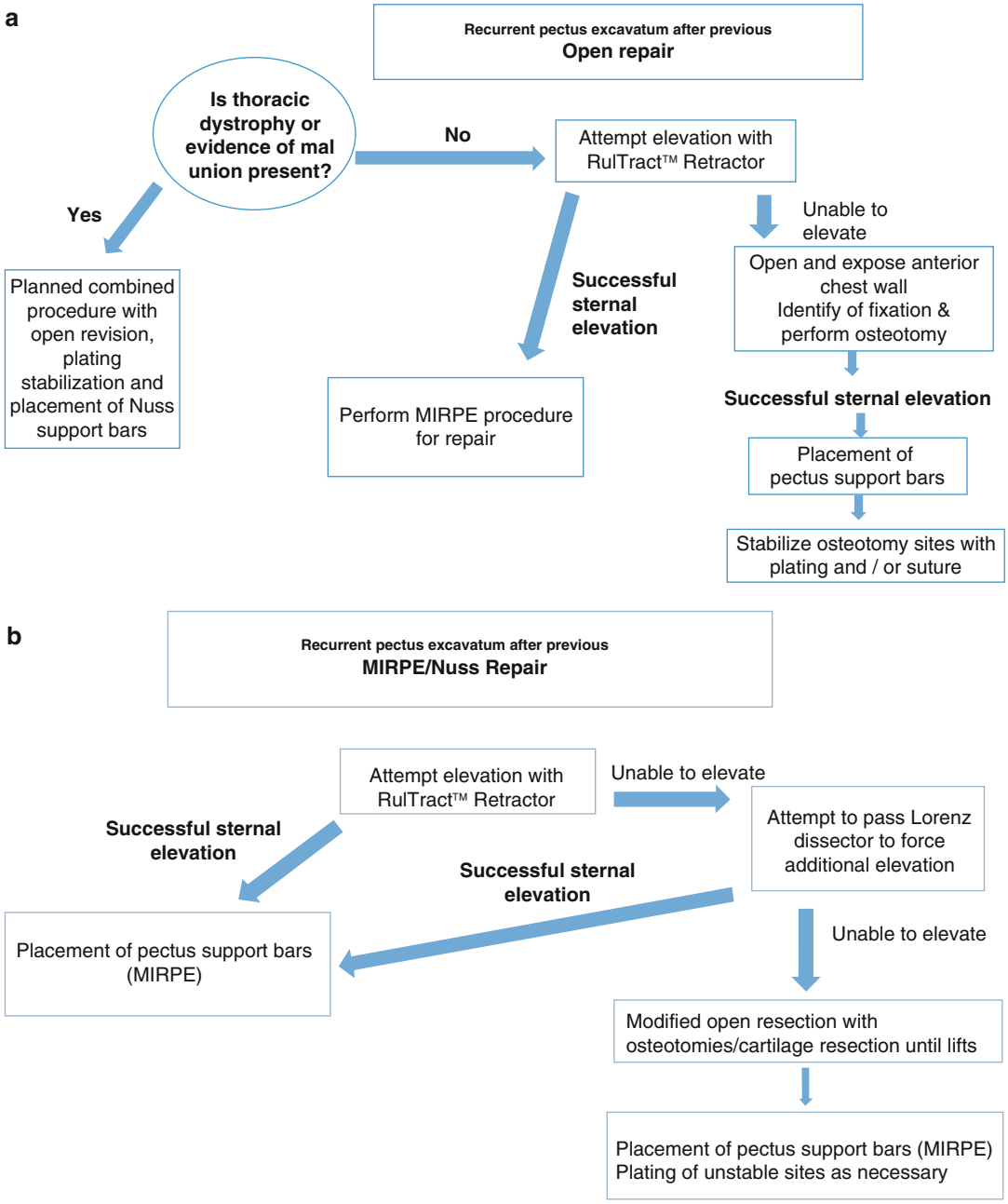

Fig. 15.11 (**a**, **b**) Algorithm for surgical approach to recurrent patients (**a**) previous Nuss/Minimally invasive pectus excavatum repair (**b**) open repair

and shaped for individual patients. Bars are flipped into place with the sternum still held elevated to minimize stress lateralized to the intercostal space. Bilateral circumferential fixation of the bars around the rib using FiberWire® (Arthrex Inc, Naples, FL) is performed. The technique for this has been previously published [93]. Two or three sites of fixation are performed bilaterally for each bar. Fixation should incorporate the islet of the bar bilateral and incorporate a rib either

Table 15.5 Procedure for revision of prior Nuss and open PE recurrence

1. Attempt thoracoscopic MIRPE with forced sternal elevation with RulTract™
If able to achieve lift and no malunion, MIRPE is performed with adherence to principals of multiple, properly positioned, stabile bars for support
If unable to elevate successfully or evidence of malunion or sternal floating:
2. Prior open surgical incision is reopened or midline incision made and muscle flaps elevated to expose the anterior chest wall. Evaluation for sites of restriction to elevation are identified
3. Removal of deformed costal cartilages is performed at sites preventing elevation only. An anterior wedge osteotomy of the sternum and osteotomy cuts of fused sites are performed where required until anterior elevation of defect possible
4. Thoracoscopic placement of sternal support bars in 2–3 sites balancing defect is performed for MIRPE repair
5. Selective anterior stabilization of sternum, sternocostal nonunion and pseudoarthroses is performed utilizing titanium plating and FiberWire

Fig. 15.12 All reoperative recurrent pectus excavatum patients are positioned supine with arms tucked at the sides and groins exposed should emergent cardiopulmonary bypass be necessary. This positioning facilitates access to both anterior and lateral aspects of the chest wall for placing and affixing bars

directly below or on either side of the bar. A second and sometimes 3rd site of fixation should be placed more medial on each side closer to the rotational fulcrum depending on the pressure and stability of the bar placement. A small right angle is used to pass the FiberWire® suture through the intercostal space just above a rib and directed towards the apex. The suture is again grasped by

Fig. 15.13 Elevation with the RulTract Retractor (Ruletract Inc., Cleveland, OH) attached to the table at the level of the mid-sternum on the left side is attempted. A perforating tips bone clamp (Lewin Spinal Perforating Forceps, V. Mueller NL6960; CareFusion, Inc, San Diego, Calif) and attached to the retractor

passing the right angle inferior to rib. The suture is then securely tied over the bar lying partly in the grooves.

If Forced Sternal Elevation Cannot Elevate the Chest Anteriorly or Malunion and Sternal Floating Evident

Procedure for Combined Open and Modified Nuss for Revision

If forced sternal elevation cannot elevate the chest anteriorly or malunion and sternal floating evident, the midline incision from patient's previous open procedure is excised and dissection taken down to the bony chest wall. Sites of calcified restriction or malunion are identified. If cartilage and perichondrium remains, a limited cartilage resection is performed. These techniques are similar to those used in the modified

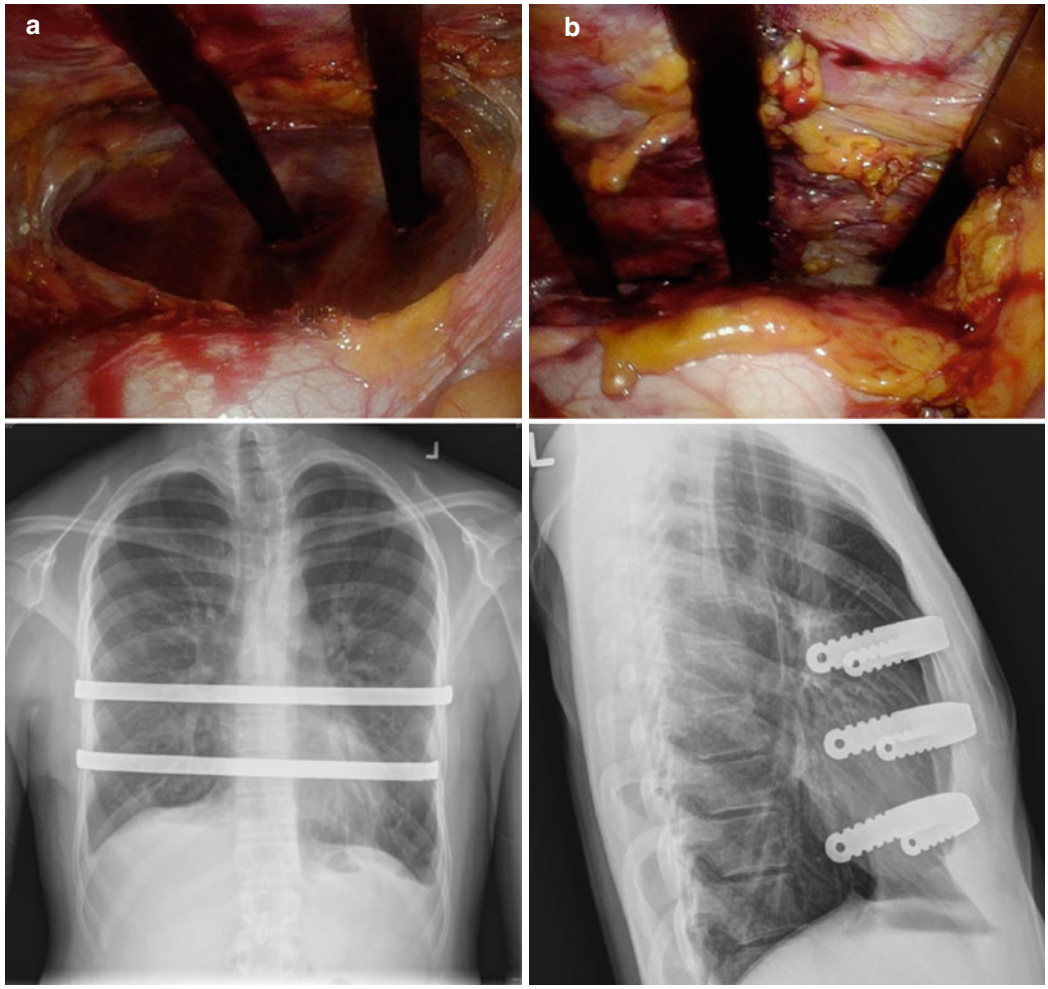

Fig. 15.14 (**a**, **b**) Intraoperative photograph and chest roentgenograms showing the placement of 2 and 3 Nuss support bars for repair of pectus excavatum deformity

Ravitch repairs, but are limited to areas that will not elevate and in sites with persistent malformation following elevation. For many patients, osteotomy of the sternum and improperly positioned, fused ribs may be required due to extensive scar tissue and calcification. In these scenarios, multiple osteotomies may be required at fixed sites and the sternochondral junctions using bone chisels or a powered bone saw.

Once chest mobility is obtained and anterior elevation is obtained with the RuleTract, exploration and takedown of the mediastinum is thoracoscopically performed. A combination of electrocautery and blunt dissection of pleural and mediastinal adhesions is performed. In cases with significant pericardial adhesions to the sternum, a subxiphoid approach is additionally used for direct takedown of scar tissue by pulling the sternum upward and looking directly. Others have also reported using this approach to safely dissect thru the adherent mediastinal structures [5, 13, 31]. Once the dissection is complete, the Lorentz dissector (Biomet MicroFixation, Jacksonville, FL) is passed across from the right interspace to the contralateral side for guided placement of the support bars (Fig. 15.15). The procedure as previously described is performed for placement of 2–3 support bars and FiberWire securing.

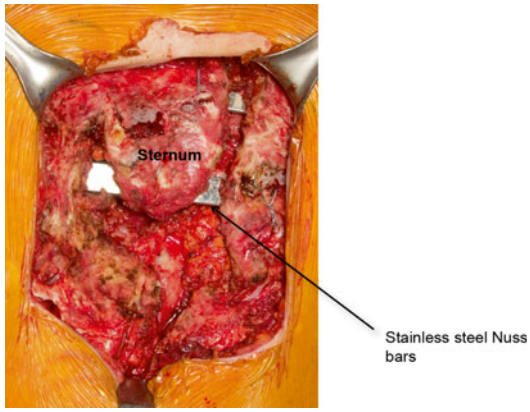

Fig. 15.15 Intraoperative photograph of patient with recurrent severe pectus excavatum after open Ravitch. Extensive malunion is seen. Areas of pseudoarthrosis and fibrous malunion are debrided back to healthy tissue. Stainless steel pectus bars are placed to elevate and support the chest anterior. Bone graft and plating will then be utilized to further stabilize and repair these sites

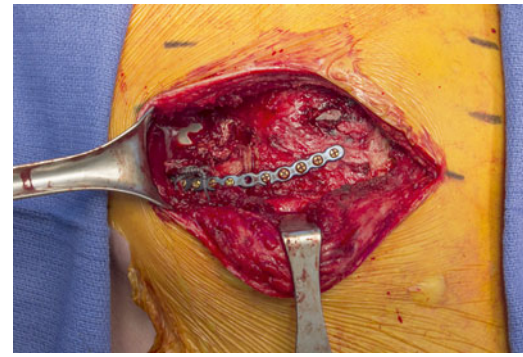

Fig. 15.16 Intraoperative photograph of titanium plating utilized to secure a site of malunion after failed Ravitch procedure

Fig. 15.17 Chest roentgenogram is shown of patient postoperative from revision procedure after recurrent Ravitch. Sites of malunion were stabilized with titanium plates. Two support Nuss bars were utilized

Extensive calcification of the chest wall following repair can be equally debilitating following open repair. Correction of this condition is extremely difficult, with the concern that any subsequent repair may result in a similar result as scarring occurs following operative intervention. Osteotomies of the sterno-costal junctions, as well as osteotomies more laterally along the ribs may be necessary to mobilize the anterior chest wall. Repeated osteotomies in similar locations are prone to malunion or non-union, which has led to our use of titanium plating or Fiberwire to stabilize these areas. Open repair can also lead to disruption of the blood supply to portions of the bony portions of the chest wall, which can lead to sections of the chest wall that are absent. These areas are difficult to stabilize, and titanium plating is at times necessary to restore chest wall stability [34, 37]. Titanium sternal plating (Biomet Microfixation, Jacksonville, FL and DePuy Synthes) and FiberWire fixation is then utilized to approximate the sites of costocartilage/rib to the sternum following elevation. Plates are chosen based on length and shape to best accommodate the fixation (Figs. 15.16 and 15.17). Multiple plates are utilized for all unstable areas and FiberWire for attachment to the sternum at other sites. For more extensive deformities with osteonecrosis and extensive chest wall hernia, use of cadaveric bone graft, methylmethacrylate and biologic mesh can be utilized for repair. These more extensive techniques are covered in previous publications [32, 33].

Support bars are securely affixed to the chest wall and then the sternum is released and the bone clamp removed. The pectoralis muscles are

reattached to the chest wall covering the bars and incisions closed with layered absorbable suture. A single approximating stitch is placed on the sites of the clamp insertion.

Once the chest wall defect is completely corrected, the pectoralis muscle and fascia, as well as the rectus abdominus muscle and fascia are reattached to the chest wall. The incisions are closed with layered absorbable suture. Chest tubes are placed through the lower port site on the right and left if deemed necessary.

Conclusion

Recurrence of pectus excavatum deformities occurs after both open and MIRPE. Recurrence risks are based on multiple factors and differ based on the initial repair procedure. Identifying the sources of a previous procedure's failure is critical to preventing the recurrence. Surgeon experience with the type of procedure is also important as reoperative cases can be difficult and are prone to increased complications. Complete correction of the pectus defect may not possible with MIRPE alone, and a combination of surgical techniques may be necessary in many patients. Each case must be taken on an individual basis based on that patient's anatomy and previous repair technique.

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