Pectus Excavatum

17

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Abstract

Pectus excavatum (PE) or funnel chest is a dorsal deviation of the sternum and most commonly the third to seventh rib or costal cartilages, resulting in a concave depression of the anterior chest wall. Depending on the severity of PE, deviation of the thoracic organs and spinal deformities (such as scoliosis in 15–21% of patients) may also be present. PE is the most common congenital chest wall abnormality and has an incidence of 1 in 260 births among white infants, 1 per 1400 births among black infants and 1 in 500 in 'other' infants. Males are more commonly affected, with a male to female ratio of 4 to1. Autopsy records report PE in 1 of 800 cases. Survival analysis indicates that PE patients tended to die earlier. However, PE patients who survived past the age of 56 years tended to live longer than matched controls.

Keywords

Pectus · Ravitch · Nuss

Pectus excavatum (PE) or funnel chest is a dorsal deviation of the sternum and most commonly the third to seventh rib or costal cartilages, resulting in a concave depression of the anterior chest wall. Depending on the severity of PE, deviation of the thoracic organs and spinal deformities (such as scoliosis in 15–21% of patients) may also be present. PE is the most common congenital chest wall abnormality and has an incidence of 1 in 260 births among white infants, 1 per 1400 births among black infants and 1 in 500 in 'other' infants. Males are more commonly affected, with a male to female ratio of 4 to1. Autopsy records report PE in 1 of 800 cases. Survival analysis indicates that PE patients tended to die earlier. However, PE

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patients who survived past the age of 56 years tended to live longer than matched controls.

A positive family history is present in up to 40% cases. Family tree analysis has shown that inheritance can be been autosomal dominant or recessive or X-linked or multifactorial in different families. A third present in infancy but the majority do not notice the depression until the pubertal growth spurt.

Although the exact aetiology of PE is unknown, abnormal mechanical forces during growth are thought to contribute to its development. This is supported by co-presentation with congenital diaphragmatic hernia, following costal cartilage graft harvesting, accompanying upper airway obstruction and in untreated infants with spinal muscular atrophy.

Histologically cartilages removed at surgery appear unremarkable, but mechanical deformation properties of the cartilages, electron microscopic findings and abnormal collagen content have also been reported. Indeed there is an association of PE in patients with a connective tissue disorder, namely, Marfan syndrome (5–8%), Ehlers-Danlos syndrome (3%) and Sprengel's deformity (0.6%).

Surprisingly the earliest reported cases come from a report from Hungary of 2 PE sternums found in a collection of 48 breast bones in graves dated from the tenth to the sixteenth centuries.

Sauerbruch, one of the pioneers of thoracic surgery, reported a case in 1913 of PE treated surgically by excision of a section of the anterior chest wall, including the left fifth to ninth costal cartilages and adjacent sternum. Preoperatively the patient was incapacitated by severe dyspnoea and palpitations, which resolved following surgery. At this time surgical treatment carried significant risk of death. Ravitch's modification more than 20 years later led to wider adoption; the technique included bilateral subperichondrial costal cartilage resection, sternal fracture, complete detachment of the sternum from its attachments below the second or third costal cartilage and placement of a substernal bone graft. Gross noted good correction with only division of the costal cartilages in two places and sternal osteotomy, and Welch reported excellent results without cutting through the intercostal bundles or rectus muscle attachments. Internal support was suggested later and included either homologous rib (Dorner, 1950), curved steel bar through sternum (Wallgren & Sulamaa, 1956) or shorter bar posterior to the sternum (Adkins & Blades, 1961). More recently used support materials include titanium miniplates (our preferred technique), Dacron vascular graft strut, bioabsorbable substernal mesh band. The use of silicone implants for primary correction is not advisable as it does not correct the underlying chest deformity. The sternal turnover technique has not been widely adopted across the world except in Japan because of fear of sternal necrosis and/or infection.

In a small number of reports, following modified Ravitch surgery, concern grew over cases where costal cartilages were replaced with bony, inflexible scar leading to poor results. At around that time, the 10-year experience of a new 'minimally invasive' technique was described (Nuss, 1988) using an internal stainless steel brace and no costal cartilage resection or sternal osteotomy reliant on flexible pliable Pediatric and adolescent skeleton and remodelling of the chest. The technique

has since been modified to include the use of video-assisted thoracoscopy, stabilisation of the bar by absorbable suture or bar attachments and special instruments to facilitate dissection. Most recent prospective studies demonstrate that repair by either Nuss or open operation can be achieved with good outcomes and minimal complications.

17.1 Assessment of the Adult and Adolescent Patients with PE

The journey of referral by primary and secondary care physician is usually fraught with difficulty for the patient. Many patients are told that it is a 'cosmetic' operation, that nothing can be done and that surgery involves a high risk of death and routine prolonged admission to intensive care. Barriers to referral are set to increase as the strains on health-care resources aim to push this condition into a group perceived to be of 'low clinical value'. This is far from the truth as many young lives are transformed by this surgery allowing them to live and contribute to society fully. Even consultation with cases of minor severity is important: Reassuring patients that they can carry on with life without concern or worry is worthwhile. The other end of the information spectra is the wide number of pectus forums. Whilst some of them provide valuable support and information for the patient, a number are misinformative.

Tip

One way to deal with this gap in information is to develop your own bespoke patient information. A website which highlights indications for, what to expect and pictures before and after, and videos of patient experience of surgery is a valued resource. With this approach we have found that patients who use our website (www.pectus.co.uk) tend to be more satisfied after the surgery. Also keeping an album of anonymised photos pre- and post-surgery of treated patients not only serves as part of the clinical records but allows patients considering surgery to understand what they can expect from repair of their pectus.

A thorough history and examination is essential as is a frank discussion about expectations for surgery. Success of the surgery relates to how the patient feels about his physical status and the appearance of the repair not the clinicians perception of it. There are times when the cosmetic result of the surgery is not perfect from the surgeon's perspective but the patient is very pleased with the result.

Tip

In our clinical practice, we see patients and their families twice before the decision to undergo major surgery is made. The consultation is summarised in writing to the patient to be clear about the expectation of surgery. 'Improving the look of the chest but never making it perfect…. the more severe usually the more satisfied with surgery…. trading one look for scars' are all useful phrases. The recurrent underestimate in a young person's mind of what suffering they have to undergo with the surgery specifically around pain requires special attention in the consent procedure.

Symptoms broadly speaking are twofold physical or psychosocial, and both need to be explored thoroughly.

Compression of the thoracic organs may result in chest pain, fatigue, dyspnoea on exertion, recurrent respiratory infections, asthma symptoms, palpitations or syncopal episodes. It's important in sedentary individuals to elicit whether behaviour is triggered by limitation in exercise capacity or not. It's not unusual in patients who do not complain of any limitation in physical activity to find after surgery that they are able to do more. This is backed up with evidence; meta-analysis of studies showed that cardiovascular function increased by greater than one half standard deviation following the surgical repair of pectus excavatum despite including studies that measured change in the deconditioned early post-operative period. Direct cardiac compression may result in reduced cardiac output due to a reduction in stroke volume. The degree of severity of PE, however, does not correlate directly with functional impairment perhaps because of the way we define severity. In some PE patients with a deep chest (increased anteroposterior distance), the heart may never be compressed despite severe sternal depression. Improvements in cardiac function especially during exercise (including ejection fraction and right ventricular systolic and diastolic indices) have been reported both in the early post-operative period and long-term following surgical correction. Mitral valve prolapse, as a direct result of cardiac compression, is more prominent than in an age-matched population (17% PE vs. 1% normal population). Dysrhythmias, including first degree heart block, right bundle branch block or Wolff-Parkinson-White syndrome, may be present in up to 15% of patients. Congenital heart disease is present in 2% of patients with PE. Thus a thorough examination of the cardiovascular system is warranted.

The body of evidence showing impairment in spirometry and improvement with surgery has also become clearer in recent years. Both spirometry (measurement of air flow out of the chest on exhalation at rest) and plethysmography (measurement of lung volumes) are usually reduced by approximately 10–20% of the predicted values. For forced vital capacity, forced expiratory volume (FEV) in 1 s and FEV 25–75%, 26%, 32% and 45% of patients, respectively, are in the abnormal category that is below 80% predicted values; with a normal distribution, only 16% should be less than 80% predicted. As these are otherwise healthy patients usually without concurrent pulmonary disease, with pliable chest walls and large physiologic reserve, the abnormal respiratory function may only be unmasked by formal exercise testing. In older patients with symptoms that seem out of proportion with their pectus, other causes should be sought.

Chest wall motion capture technology has enabled a more detailed valuation of the effects of PE on respiratory mechanics. In summary, the bellow action of the ribcage is impaired with PE. Normally, the sternum should move up and down like an old-fashioned water pump, with PE the lower end of the sternum is fixed and the patients compensate by increasing abdominal breathing. This pattern is corrected following repair. This idea is supported by the finding that patients with the more severe depression are more likely to have a restrictive pattern of spirometry.

Technical Tip

One caveat to modest changes in primary PE is the observation of significant restrictive lung function that can occur in recurrent PE with spirometry values about half of predicted values.

17.1.1 Psychosocial

It is important to document the effects of PE in these patients in terms of mental health—anxiety and depression, self-esteem, quality of life and body image. The key is to try and discern how much or many of these symptoms are ascribable to PE. This can at times be difficult to assess for surgeons and if there is any doubt, specialist psychological help is required. Increasingly with financial constraints on the health systems, we must quantify the baseline and any improvement. Using psychometrically validated testing tools is essential in this respect. Studies have shown consistently that there is marked improvement in psychosocial functioning following surgery; interestingly this is independent of the severity of the PE. There can be an apathy of clinicians towards these symptoms which present in a person's life just when they are establishing an independent identity and interacting with others. This deformity reduces capacity to do those things and is very significant within these young people's lives. The Medical community support surgical treatment of syndactyly, revision of burn scars, cleft lip and other conditions where the justification is 'cosmetic'; PE is no different in actual fact and reasons to correct are far more established.

Tip

We prefer to use more than one tool as all aspects may not be covered adequately in just one questionnaire. Our current practice is to institute at the first clinic visit the Patient Health Questionnaire (PHQ-9) screening, diagnosing, monitoring and measuring mental health and the generalised anxiety disorder (GAD-7) in addition to the Nuss questionnaire. In our experience these questionnaires have value in assessing patient's symptoms and bringing out issues that sometimes can be difficult to elicit in consultation. It's also important to discern if there are significant underlying mental health issues that may not improve following surgery. In these cases, there should be a low threshold to seek a formal psychological consultation.

Examination should note the variant concavities of the anterior chest wall listed in frequency order: focal or cup-shaped deformity, broad, shallow, saucer-shaped deformity, long furrow or trench deformity, (which is usually asymmetrical) or mixed pectus carinatum and excavatum. The body habitus of a tall, thin patient with forward-drifting hunched shoulders in an attempt to hide their PE is common. In these patients, it's important to stress the importance of the preoperative programme of physiotherapy of back straightening exercises. This is especially important because if patients maintain a poor posture following surgery, this may contribute to recurrence. Any asymmetry of the PE and associated sternal tilt as well as costal flaring should be documented. This is especially important as sometimes costal flaring may be more troublesome to the patient rather than the dip in the sternum itself.

In women especially note any asymmetry in breast tissue: this can become more marked following correction. Failure of bra's to fit correctly is not an uncommon complaint in female patients.

Tip

Performing a Valsalva manoeuvre, getting the patient to push their chest forward having taken a deep breath in gives an idea of the flexibility of the chest which plays a role in deciding which type of operation would suit the patient.

Note must be taken to the quality of the skin, specifically how well the skin heals from old scars and other coexisting skin conditions such as acne. These can be an indicator of risk for hypertrophic scar formation. Finally features of connective tissue disorders, scoliosis (fixed or reversible), joint laxity and striae may also be present. The presences of scoliosis should also include a test to see if it's fixed or not. Heart murmurs should be excluded, particularly mitral valve prolapse. Nickel allergy occurs in 2% of the population and may be suggested by the absence of wearing a metal backed watch or jewellery. Formal allergy test should be performed if history suggestive and plan for titanium implants rather than stainless steel if the test is positive.

17.2 Investigations

Chest radiograph may demonstrate a concavity in the anterior chest wall. Computed tomography (CT) and magnetic resonance imaging (MRI), however, are better at demonstrating bony and cartilaginous deformities, with the cephalocaudad extent of the depression more easily visualised and cardiac or pulmonary compression and displacement.

Radiological imaging is also important to aid the planning of surgical intervention. In recurrent PE calcification following open repair can be a marker of fixity of the chest.

The Haller radiographic index is defined as the internal lateral transverse thoracic diameter divided by the anteroposterior diameter (shortest distance from the back of the sternum to the front of the vertebral body) (Fig. 17.1). A Haller index

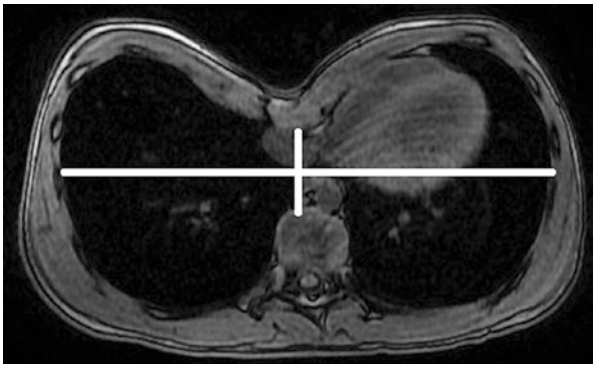

Fig. 17.1 Axial computed tomography image demonstrating the calculation of the Haller index by dividing the internal lateral transverse thoracic diameter by the anteroposterior diameter

above 3.2 represents severe PE, though as mentioned before, the morphology of the chest may not be captured fully by a single measure. The deep depression in a barrel-shaped chest may have little physical compression of the heart. Review of the CT scan with the patient and family before surgery is a useful exercise as it helps to communicate the extent of deformity and its effects as well as potential complications of surgery. MRI may be used instead of CT to reduce radiation exposure, but because more claustrophobic and longer scanning times may not suit all.

If a patient has physical symptoms, then our recommendation is to perform baseline echocardiography and lung spirometry. There is a trend to perform these tests in all patients undergoing surgery though this practice has recently been challenged.

17.3 Criteria for Surgical Repair

Only around half of patients presenting to the surgical team are offered surgery. Minor cases of pectus should be reassured and discouraged from surgery. A programme of physiotherapy can be helpful, and there are reports of some patients who have been successfully treated with vacuum bell devices.

Generally speaking the criteria for offering surgical treatment in patients with severe pectus (Haller index greater than 3.2) should be guided by the presence of psychosocial or physical symptoms. There is a trend for some surgeons to encourage treatment in asymptomatic patients with evidence of cardiac compression on CT or paradoxical motion with deep inspiration, restrictive pulmonary function test, mitral valve prolapse and bundle branch block.

Evidence to recommend major surgical treatment in the asymptomatic patient is sparse though most patients with severe pectus do have symptoms.

No effective validated conservative methods have been described for the treatment of severe PE; surgery remains the only therapeutic option. The most common surgical options include:

(a) Open repair—modified Ravitch procedure (Fig. 17.2)
(b) Minimally invasive repair—Nuss procedure (Fig. 17.3)

The timing of surgical intervention, however, remains controversial. Performing the Nuss or Ravitch procedure before the pubertal growth spurt may necessitate redo surgery as the patient grows the pectus may recur. In the UK, the optimal age for minimally invasive repair is thought to be between 14 and 18.

Choice of operation depends on the flexibility of the chest, patient choice and expertise of the surgeon. Valsalva manoeuvre can assist with this decision. In general Ravitch is offered in patients who are older when the flexibility of the chest reduces and in patients with combined PE and carinatum defects, pouter pigeon deformity with anterior displacement of the manubrium and posterior displacement of the body of the sternum and significant sternal torsion. Prior to surgery, patients are instructed on maintaining good posture and exercises to perform before and

Fig. 17.2 Pectus excavatum, before and after operative repair using (**a**) a modified Ravitch (**b**) Nuss procedure

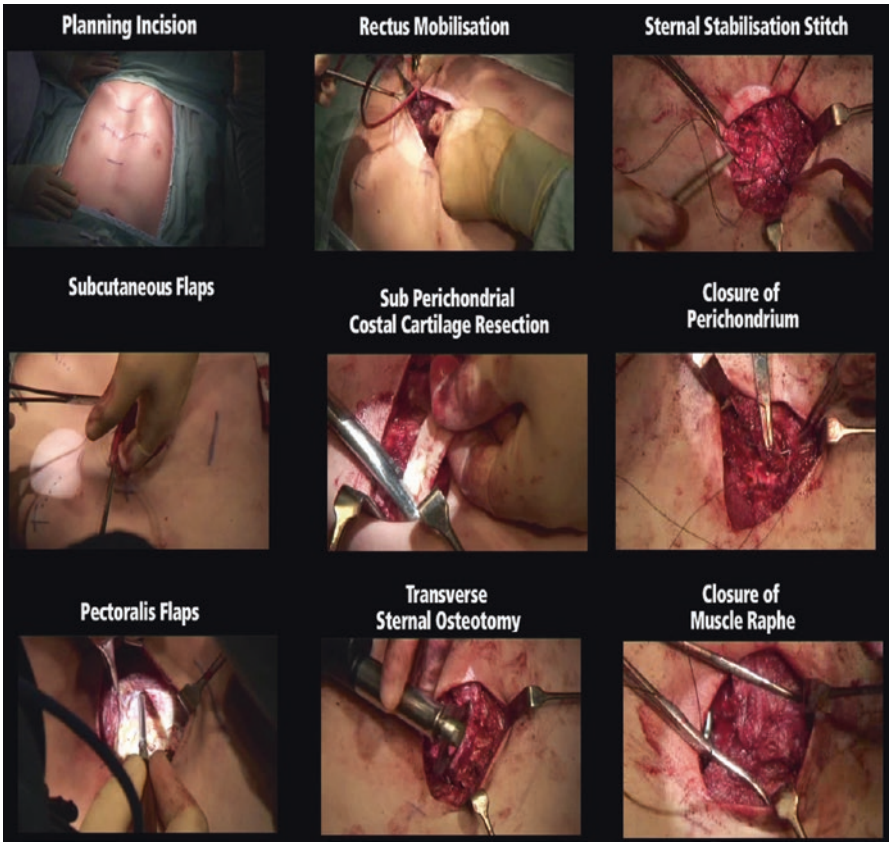

Fig. 17.3 Operative images demonstrating the modified Ravitch procedure

after surgery. They must understand what to expect before and after surgery, and a clear list of dos and don'ts after surgery is valuable in facilitating a complication-free patient journey.

17.4 Modified Ravitch Repair

Careful planning of the incision and extent of resection is required before starting the procedure (Fig. 17.4). The principle of the surgery is to dissect tissues to reach the desired position of the chest wall in a tension-free manner. Placing a transverse incision (our preference) in the midpoint cephalocaudad of the extent of cartilage excision facilitates exposure and limits the size of the incision. This may not always be at the deepest point of the PE.

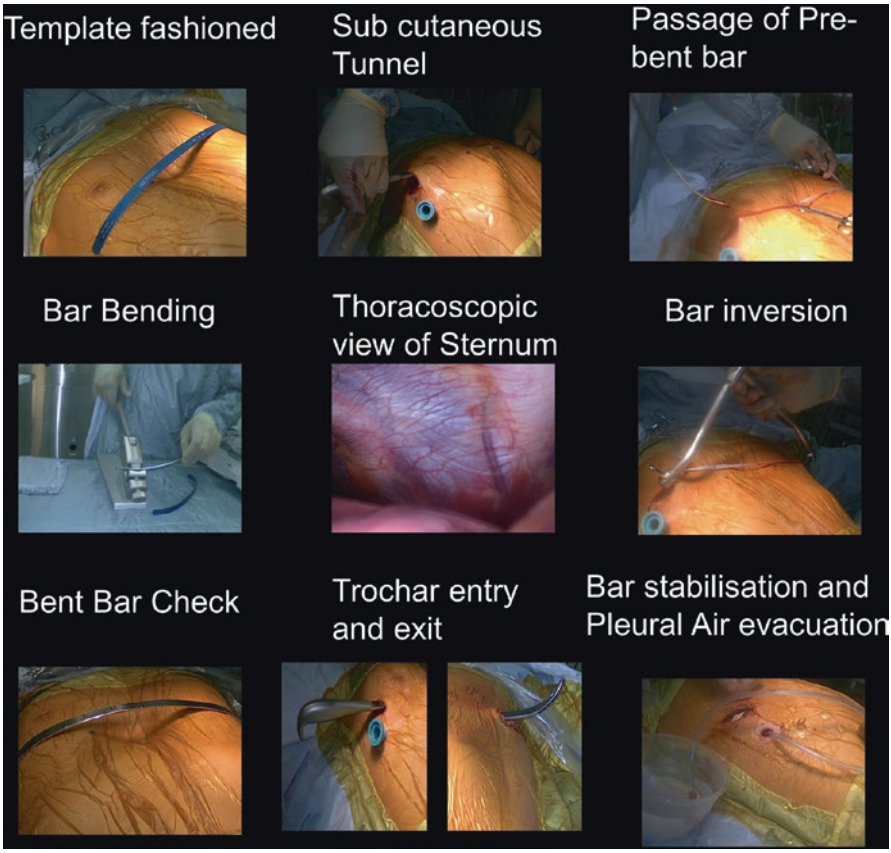

Fig. 17.4 Operative images demonstrating the Nuss procedure

A 6–8 cm transverse skin incision is made, and elevation of subcutaneous and then pectoralis and rectus muscle flaps to the extent of the deformity is performed. It's important when raising these flaps in a thin individual not to button hole the skin nor extend dissection under the nipple which can lead to denervation. The muscle flaps are elevated until they can oppose to the midline without excessive tension. Bilateral subperichondrial resection of deformed cartilages, transverse sternal osteotomy and xiphisternum excision if required are performed as required to allow the sternum to return to a 'neutral' or desired position. Minimal cartilage excision (1–3 cm) adjacent to the sternum followed by multiple chondro-/osteotomies more laterally allow the shape of the chest to be achieved from the outset with good stability rather than excision of larger sections of cartilage which then rely on regrowth of cartilage. This technique can also be used to deal with costal flaring. Anecdotally with this technique, the drainage of serosanguinous fluid is diminished, and it aids faster recovery and discharge from hospital. Scoring the perichondrium at the site of excision in a wide 'H' allows the perichondrium to be pushed off the underlying cartilage. Getting in the right plane results in a relatively bloodless dissection. Going

round the back of the cartilage can be precarious as damage to the internal mammary artery or worse the heart may occur if the elevator slips. Thus the technique is always to ensure the direction of pressure, and dissection is away from the deeper structures, i.e. outwards. Once dissection round the back of either the lower or upper edge is done, lifting up with the elevator whilst dissecting the other side with a second elevator facilitates dissection. Once around the cartilage in a subperichondrial plane, this can be extended along its length by using a 'Doyen' costal elevator and applying lateral traction which strips away the perichondrium. It is best to leave all cartilages in situ and complete the dissection as once a cartilage is removed the dissection of the next cartilage is impaired by the lack of resistance provided by the surrounding cartilages. Once all dissected the medial ends are released with either lateral traction with a Doyen costal elevator or dislocated anteriorly at the junction with sternum either with sharp or blunt dissection. At this point the 'fingers of cartilage' overly the sternum. The shortening of these should be done following the osteotomy and repositioning of the sternum.

The osteotomy of the anterior table of the sternum is performed at the point that the sternum starts to dip down and the cartilages below this point are the ones excised. Thus the importance of planning before the skin incision is made where this point is going to be. The idea is to allow the sternum distally to pivot and thus attain the desired position with minimal substernal dissection. Wedge excision osteotomy is used to elevate the distal sternum in cases of excavatum. In cases where there is sternal torsion, more bone is removed from the side which dips more. The sternum is then fixed in the desired 'neutral position'. Our preferred options are to do this with either heavy absorbable sutures in symmetric cases or in more complex or asymmetric cases with a small titanium 'H' sternal plate.

With the first technique, two heavy absorbable sutures (looped '1' polydioxanone (PDS)) are placed across the osteotomy to hold the sternum in place. Slight asymmetric tilt in the sternum can also be corrected by the differential positioning of the two sternal tables at each end of the osteotomy by these two sutures. An additional heavy suture is placed through the distal body of the neutrally placed sternum and later secured to the overlying pectus muscle raphe for additional stability.

Self-tapping screw with the 'H' plate makes insertion easy requiring little additional equipment. The plate can be bent to the desired position to correct for the tilt. Size of screws is determined by a depth gauge. Attachments of the perichondrium and other soft tissue tethering the sternum are divided.

At this point the pre-dissected cartilages are shortened to allow reattachment to the sternum with heavy absorbable sutures. Always removing a little more than you think is required so that the cartilages once re-approximated to the sternum are under slight tension. But prior to this further lateral osteochondrotomies/osteotomies are made to recontour the rib cage. Usually these are made at the angle where the rib suddenly bends. Sometimes multiple osteochondrotomies are required to straighten the rib. The perichondrium is re-approximated where possible. In this 'minimal cartilage' excision technique, the rib cage contour is intact, and minimal regrowth is required to remodel the shape of the chest as compared to a traditional Ravitch operation.

Tip

The pectoralis and rectus muscles are re-apposed in a midline 'Mercedes' sign raphe. Thus the importance of freeing up enough of the muscle in the initial dissection to allow a tension free apposition. At this stage, the body of the sternum is fixed to this raphe using the previously placed suture. Submuscular and subcutaneous drains are placed to allow adequate drainage of blood. The skin may look rather bruised after all the dissection, but this settles down within a few weeks. The midline ridge of the opposed pectus muscles is also noted by patients which again flattens over a few months.

Previously we have used metal bars to support the repair, but fracture and displacement led us away from this technique. Others have used slings of mesh or graft to support the repair.

17.5 Nuss Operation

Our preference is to use a pre-bent bar which is based on the CT scan dimensions. These nowadays do not cost any more than the bars which are bent at the time of surgery, and they require less readjustment once 'inserted'. In patients with nickel allergy, a prebent titanium bar should be used.

There are three commonly used patient positions: supine with either both arms abducted at the shoulders to approximately 70°, taking care to protect the patient from brachial plexus injury; elevating the torso and extending the arms posteriorly, but this can lead to overextension of the chest during the surgery; or finally flexing the left shoulder and elbow anteriorly and holding it above the head, but there are anecdotal reports of brachial plexus injury with this position too. Our preference is for the first position.

Thoracoscopy is used to guide bar placement usually from the right side. In patients with severe PE, it may be necessary to use bilateral thoracoscopy because the heart is displaced to the left, which impedes visibility from the right. Care must be taken during insertion because of the displaced heart. Generally the scope is inserted one space below the incision, and a 30° scope is preferred as it allows for looking 'round the corner'. It can also be inserted through the incision or even superior to the incision site. Following entering the pleural cavity with a blunt small clip to induce a pneumothorax, we direct the trocar insertion in a superior direction to avoid the diaphragm. Carbon dioxide (CO_2) insufflation pressure is useful in collapsing the lung and facilitating mediastinal dissection. Pressures are kept low between 5 and 6 mmHg. Leakage increases once the trocar and then bar are inserted thus higher flow rates may be required at this time.

The bar is usually sited at the deepest portion of the pectus unless this is inferior to the body of the sternum. A bar placed at this point will not be seated below the bone (just xiphisternum) and on removal is associated with high recurrence rates. Two small lateral thoracic incisions at the anterior axillary line provide good access to the thoracostomy entry and exit sites. Incisions that run parallel to the ribs require the least amount of subcutaneous dissection and are less likely to cause a keloid

reaction. Vertical incisions in the mid or posterior axillary lines can give poor access to the anterior chest wall and tend to cause keloid formation. The exact position usually at the deepest portion of the pectus is guided by placing the pre-bent bar at the site of insertion and centering the incision 1 cm distal to the tip of the bar to compensate for the internal rather than external positioning. Equally if not using a pre-bent, the site of skin incision is marked, and a malleable guide is downsized 2 cm and fashioned to the desired contour of the chest then used as a template to bend the bar using the table top bar bender. It is important to slightly overcorrect the deformity to prevent buckling of the anterior chest wall and to decrease the risk of recurrence. The bar should therefore be semicircular with only a 2- to 4-cm flat section in the middle to support the sternum. If the deepest point of the deformity is inferior to the body of the sternum, two bars may be required: one under the sternum and the other under the deepest point of the depression. When placing two or more bars, making a separate incision for each bar facilitates bar stabilisation and bar removal after 3 years. Two bars may also be used in older patients who have less compliant chests with wide-type defects to achieve a better cosmetic result. In mature female patients, the incisions should be placed in the inframammary crease between the 6- and 9-o'clock positions, and this gives an excellent cosmetic result.

A subcutaneous pocket 360° around the incision is made to make room to seat the stabiliser, and this is followed by a subcutaneous or submuscular tunnel slightly wider than the bar heading to the sternum to the point of entry into the chest and slightly beyond, thereby preventing tethering of the skin once the bar is inserted. It's important to ensure that the dissection does not button hole the skin and use of long thin retractor can be useful. If the correct plane is followed, there should be minimal bleeding. The thoracic entry and exit sites are just medial to the pectoral ridge externally and so is close to the sternum to prevent disruption of the intercostal muscles. Three trocar or introducer sizes are usually available for adults; the medium or larger size is appropriate. The trocar is inserted through the tunnel with the curve pointing downwards, and this is pushed through into the pleural cavity under direct thoracosopic vision. The trocar is flipped so that the tip is now pointing up to the sternum. The trocar tip should always be kept in view during the tunnelling, and in a pawing action is passed from right to left chest cavity hugging the sternum to the point of exit of the bar. The trocar tip is pushed or delivered up through intercostals and then is pushed through the subcutaneous tunnel to appear through the contralateral skin incision. During this whole process, it will be noted how the sternum has been lifted upwards. Thus the trocar is used to dissect the plane between the sternum and pericardium under direct vision and is exteriorised via the left incision. When the trocar is in position across the mediastinum, it is lifted numerous times in an anterior direction gently lifting the patient's torso off the operating table taking care not to hyperextend the neck. Pulling the sternum and anterior chest wall out of their depressed position loosening up the ligaments helps reduces pressure on bar and risk of displacement. A nylon tape is tied to the trocar end and passed to the other side of the chest as the trocar is withdrawn. The tape is used to guide the inverted pre-bent bar (with the convexity facing posteriorly) through the chest. The inverted bar is then turned 180° (with the convexity now facing anteriorly) to push the

sternum forward. The bar should sit snugly on chest. If there is a wide gap, the bar will have to be flipped back and the bar ends bent with a hand bar bender until the desired position is achieved. A second bar should be inserted if the repair is suboptimal after insertion of the first bar. In patients with asymmetric deformities, an asymmetrically placed bar may give more lift on the side of the asymmetric deformity. The correction always looks better whilst the patient is lying flat on the operating table than it does when the patient resumes normal posture because the normal thoracic lordosis is eliminated on the operating table. To prevent the bar from rotating, it may be held in place on one or both sides with a stabilising plate, which is fixed to the surrounding soft tissues with sutures. Some surgeons advocate using sutures around the ribs, with either stainless steel wire or heavy nonabsorbable material placed under thoracoscopic guidance. In our practice we have not had any need for this additional step if both ends of the bar are stabilised. Air from the pleural cavity is expelled from the thoracoscopy incision prior to extubation.

Tip

Failed previous repairs may be amenable to successful retreatment; patient expectation of the patients should be managed appropriately as cosmetic result is far less predictable. Rigidity of the chest following Ravitch is a poor prognostic indicator. Generally in patients with previous Ravitch repair with mobile chest, Nuss repair is a good option. Whilst in redo Nuss, one may encounter adhesions that preclude or make surgery dangerous. Patients should be warned of this possibility.

The pain following Nuss surgery is more severe that Ravitch thus patients usually receive an epidural and thus should be warned of the very low risk of paralysis. Though pre-emptive analgesia is desirable, we have not found it practical as patients proceed directly to the operating room from an open admission area on the day of surgery. Following surgery, paracetamol/acetaminophen, non-steroidal anti-inflammatory analgesics with proton pump inhibitor cover, low-dose benzodiazepines for muscle relaxation and anxiolysis are all prescribed prophylactically. On the second post-operative day, long-acting morphine oral agents are commenced and the epidural discontinued on the morning of the third post-operative day. Antibiotics are administered preoperatively at the time of induction of anaesthesia and continued for 5 days post-operatively to reduce the risk of wound and prosthesis-related infection. Following surgery patients are encouraged to mobilise early after surgery and undergo a rigorous physiotherapy regime. Certain activities are restricted, for example, pulling yourself out of the bed using the upper limbs. Patients are restricted from participating in severe physical activities for 6 weeks, at which time they may recommence aerobic activities, and competitive non-contact sports may be resumed at 3 months post repair and contact usually at 6 months.

Early post-operative complications include, pneumothorax requiring chest tube, surgical site infection (SSI), pneumonia, haemothorax, pericarditis, pleural effusion (requiring drainage), temporary paralysis, cardiac perforation in the case of Nuss and of course death.

SSI requires vigorous treatment consisting of wound drainage, cultures and appropriate intravenous antibiotics, followed by long-term oral antibiotics. Usually the bar does not have to be removed until planned with this approach.

Pericarditis with Nuss may be related to undiagnosed nickel allergy and presents with persistent central chest pain, malaise, lethargy, and a pericardial friction rub. The presence of echocardiographically confirmed pericardial fluid may warrant a short course of prednisone. If symptoms recur a longer course of steroids and finally replacement of the bar with a titanium bar may be required after confirmation of aetiology by nickel allergy testing. Nickel allergy may also present late with erythema of the anterior chest wall or inflammation and drainage at the incision sites. Cardiac perforation is a potential risk and can be reduced by the diligent use of thoracoscopy, if necessary bilaterally and preoperative planning by reviewing of position of the heart in relation to sternum especially in patients with severe asymmetry and/or depressions. In these cases placement of bar 1 or 2 intercostal spaces superior to the deepest point and leaving the introducer in place to keep the sternum elevated whilst creating the second tunnel may minimise the risk of injury.

Tip

In severe cases for Nuss, we routinely elevate the sternum. There are several techniques described to do this, and our preference is the Johnson et al. technique that describes the use of a scope in the right hemithorax as a subxiphoid incision is made and a plane between the pericardium and posterior sternum is created using digital dissection under vision of the thoracoscope. Using the finger, a retractor such as a Langenbeck is inserted beneath the sternum, and it is lifted creating a gap between the pericardium and sternum which improves visibility and safety. Other techniques include placement along both subcutaneous tunnels to the hinge point of a Langenbeck retractor which are then lifted; the use of the vacuum bell device, without its hand pump and directly connected to a wall vacuum source; and the crane technique, elevating the depressed sternum, by means of wire sutures threaded through the sternum to a retracting system mounted over the operating table.

Bar displacement if minor less than 20° displaced can be observed. Displacement immediately after surgery, severe or progressing, may require surgical revision. Overcorrection resulting in pectus carinatum is rare but can occur after correction of severe asymmetric defects and in patients with Marfan syndrome and may be treated with earlier bar removal and/or external brace. Persistent pain may be caused by bar displacement, stabiliser dislocation, bar being too tight or too long, sternal or rib erosion, infection or allergy. An anterior and lateral chest radiograph, full blood cell count, ESR, CRP level and nickel allergy testing will identify the cause and allow appropriate treatment.

There is a trend to the use of shorter bars and two stabilisers in a more medial position to reduce the risk of complications. Our experience is limited in this, but we have not found a huge advantage in these modifications.

Systematic review and meta-analysis of 13 comparative studies suggest no difference in total complication rate between Nuss and Ravitch procedures in the Pediatric populations, but in the adult subgroup, the Ravitch group experienced significantly fewer complications, for both overall and early complications, but this subgroup was very small. In the adult subgroups, reoperations were significantly higher in Nuss patients compared to Ravitch patients. However in our own series

spanning 20 years, we did not find this perhaps because of shorter follow-up with Nuss technique. We did demonstrate that if a patient developed an immediate post-operative complication, they had a significantly increased chance of late recurrence.

Recommended Reading

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