

Anesthesia for minimally invasive chest wall reconstructive surgeries: Our experience and review of literature

ABSTRACT

Minimal access procedures have revolutionized the field of surgery and opened newer challenges for the anesthesiologists. Pectus carinatum or pigeon chest is an uncommon chest wall deformity characterized by a protruding breast bone (sternum) and ribs caused by an overgrowth of the costal cartilages. It can cause a multitude of problems, including severe pain from an intercostal neuropathy, respiratory dysfunction, and psychologic issues from the cosmetic disfigurement. Pulmonary function indices, namely, forced expiratory volume over 1 s, forced vital capacity, vital capacity, and total lung capacity are markedly compromised in pectus excavatum. Earlier, open surgical correction in the form of the Ravitch procedure was followed. Currently, in the era of minimally invasive surgery, Nuss technique (pectus bar procedure) is a promising step in chest wall reconstructive surgery for pectus excavatum. Reverse Nuss is a corrective, minimally invasive surgery for pectus carinatum chest deformity. A tailor-made anesthetic technique for this new procedure has been described here based on the authors' personal experience and thorough review of literature based on Medline, Embase, and Scopus databases search.

Key words: Epidural anesthesia; Nuss; patient controlled analgesia; pectus carinatum; pectus excavatum; transesophageal echocardiography

Introduction

Pectus excavatum and pectus carinatum are two chest wall deformities whose conventional correction entails major surgery.^[1] Nuss technique and reverse Nuss technique (for pectus excavatum and carinatum, respectively) are two commonly performed minimally invasive surgical techniques. Their results are comparable to that of conventional surgery, with the distinctive advantage of avoiding the morbidity associated with large thoracotomy incisions.^[2] Minimally invasive repair of pectus excavatum (MIRPE) or Nuss procedure (developed in 1987 by Nuss) initially published in 1998 has become the surgical technique of choice today.^[3] It

involves inserting convex stainless steel bars retrosternally, under thoracoscopic guidance, through small lateral thoracic incisions across the mediastinum. The convexity of these bars is directed anteriorly to correct the thoracic deformity. The occurrence of significant postoperative pain, much greater than that reported with sternotomy or thoracotomy, warrants an excellent pain management program. This includes the institution of preinduction thoracic epidural analgesia, systemic analgesics, and intercostal blocks.^[4] Patient-controlled analgesia (PCA) pumps are recommended for continued postoperative pain relief. Surgical correction

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of pectus excavatum entails an improvement in cosmesis and pulmonary function. We searched Medline, Embase, and Scopus databases using keywords pectus excavatum, Nuss, and anesthesia to locate relevant articles describing advantages, disadvantages, and complications of Nuss procedure and postoperative pain relief as many articles on its anesthetic management are not available. All the relevant articles found in Google, PubMed, ePUB, and EBESCO were fully reviewed.

Symptomology and Diagnosis

Symptoms of pectus excavatum include episodic chest pain, exertional dyspnea, and reduced exercise tolerance.^[5] Symptomatic patients tend to have abnormal pulmonary function tests (PFTs) and echocardiographic abnormalities (mitral and tricuspid valve regurgitation and mitral valve prolapse).^[1,3,5-7] A noncontrast computed tomography (CT) scan of the chest gives us the Haller index, which is the ratio between the lateral and anterior-posterior diameter of the chest wall measured at the point of maximal depression of the sternum.^[8] The normal value is 2.5. Patients with an index >3.2 have marked and severe pectus excavatum and are candidates for operative correction^[9] even if asymptomatic. The concerns with pectus carinatum include pain from intercostal neuropathy and cosmetic impairment from the unsightly protuberance and respiratory compromise in a few cases.^[10-13]

Ideal Age for Elective Surgery

The current recommendations advocate the Nuss technique in patients aged 5–20 years. The ideal age has been established at 8–12 years.^[14-16] Surgical approach to the heart at the time of open-heart surgery becomes very challenging due to prior displacement and rotation of the heart to the left chest. Hence, an elective repair of the pectus deformity before open-heart surgery may be indicated in some selected adult cases.

Benefits of operating at an early age include malleability of the ribcage and smaller chest size, making the surgery easier for the surgeon and less painful for the patient.^[13] Older patients offer advantages such as ease in bar stabilization, added safety factor in thoracic epidural placement, and maturity to understand the surgical procedure and postoperative instructions, including incentive spirometry (which reduces postoperative pulmonary complications).^[15] Risk of bar displacement and degree of postoperative pain (due to reduced chest wall pliability) sharply rise after an age of 20 years.

Contraindications

Associated complex congenital anomalies (pouter pigeon breast, Poland syndrome, Marfans syndrome with scoliosis), congenital heart disease with primary cardiac dysfunction, neurodevelopmental delay, and chronic immunosuppression constitute relative contraindications for pectus excavatum surgery.^[17-21]

Surgical Technique in Brief

Three small skin incisions are made. One in the midline over the sternum to access the costochondral joints and the other two incisions on either side of the chest wall representing the points of entry and exit of the stainless steel bar [Figure 1]. The convex, stainless steel bar is placed retrosternally along the anterior chest hemicircumference in Nuss procedure for pectus excavatum correction. This causes elevation of the sternum, with remodeling of the ribs and costal cartilages.^[14,15,22-28] Preoperative CT scans and thoracoscopy at the time of bar placement are important safeguards against cardiac or pericardial injury. In pectus carinatum corrective surgery (reverse Nuss), the aim is to place the bar in a plane as close to the bone as possible and as distant from the subcutaneous tissue and muscle as achievable. Two drains are generally placed, one on either side, both of which are removed after 2 days.

The bar is usually retained *in situ* for 3 years [Figure 2]. Implant removal surgery can be undertaken as an outpatient procedure under anesthesia. Bar removal can become a prolonged procedure due to the development of extensive fibrosis. After reopening the right side of the chest (the side with the bar stabilizer) using the same surgical scar, the bar, stabilizer, and sutures are freed from the surrounding tissues and the pectus bar is pulled out of the chest [Figure 3]. An instrument resembling a bone hook is used to apply steady traction and the bar is removed with its curvature brought

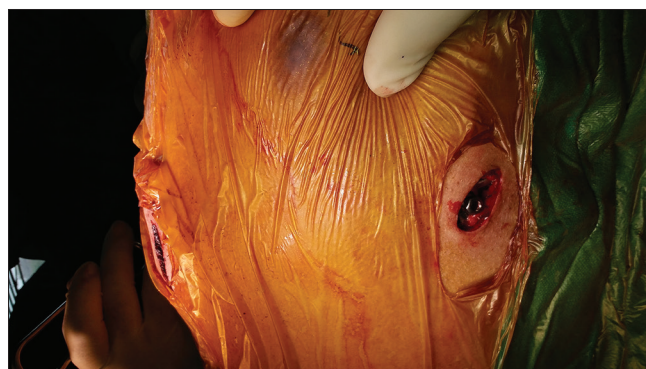


Figure 1: Intraoperative image of bar placement for pectus carinatum

almost under the operating room table. Thoracoscopy is not required for bar removal.^[14,15,23] The Nuss procedure and open surgery have comparable cardiopulmonary results at the end of 1 year, but bar removal after approximately 3 years' results in further improvement in pulmonary function above that seen with conventional surgery.^[2,28-30]

Advantages

Both Nuss and reverse Nuss techniques eliminate the need for an extensive anterior chest wall incision, resection of multiple ribs or cartilages, and sternal osteotomies. It also avoids the pectoralis muscle flap reconstruction and its attendant complications, routinely performed as part of the open surgery.^[31-33] Reduction in surgical time, blood loss, and surgical incision scar size are other important benefits.^[32-36] Moreover, the stability and strength of the chest wall are not compromised as it can be with the open repair. Furthermore, lung function at rest and during exertion are reasonably improved.^[2,29-31]

Disadvantages

Efficacy of the procedure sharply declines with increasing age (due to decrease in pliability of the chest wall).^[14] There may be significant postoperative pain lasting months (limiting strenuous physical activity).^[37] Some relapse of the deformity after bar removal may also appear.^[36] Another drawback is the inability to satisfactorily treat an asymmetrical pectus excavatum or pectus carinatum.^[14]

Complications

Over 90% of cases yield good results resulting in immense patient and family satisfaction.^[36-38] Overall incidence rate of complications was higher (almost 20%)^[14] in initial cases but

came down to <10% in later studies. This reflects the learning curve of this new technique and also an improvement in the design and strength of the bar (modified 4 times to withstand the pressure of even the most severe deformity). The most common complication requiring reoperation is displacement of the retrosternal stainless steel support bar (reported to occur in 9.5% of all patients in earlier studies and 2.5% patients in recent studies).^[14,37-39] Such displacement can include a 90° rotation, a 180° rotation, or a lateral migration. Adult patients are at higher risk for pectus bar displacement because of the increased pressure on the bar generated by a larger chest and more rigid chest cage. Factors contributing to suboptimal results include the presence of an excessively pliable bar, premature bar removal, and inadequate stabilization.^[37-39] Overcorrection,^[40] pneumothorax requiring chest tube drainage,^[40] and epidural catheter complications^[41] have each been reported in 3% of the patients. Bar allergy,^[42] infection of the surgical wound,^[43] and pleural effusion may each occur in about 1% of the patients while thoracic outlet syndrome,^[14] pericarditis,^[40] cardiac injury,^[37] and sternal erosion^[40] have each been reported in just 0.5% of the patients. Death is the rarest complication (incidence of one in 1000 patients). Liver laceration^[37] is another complication. The reported incidence of cardiac perforation during a MIRPE is rare, ranging from 0%^[3] to 0.4%.^[26]

A significant advantage of Nuss technique over the open surgical procedure is that the alarming complication of "chest wall constriction" (Jeune syndrome) has not been reported with the Nuss technique.^[16,44] The growth centers of ribs and sternum can be affected by open surgery causing restriction of chest wall growth and severe limitation of respiratory function. The forced vital capacity and forced expiratory volume in 1 s ranged from 30% to 50% and 30% to 60% of predicted levels, respectively, in a study^[16] on open pectus excavatum surgery patients.

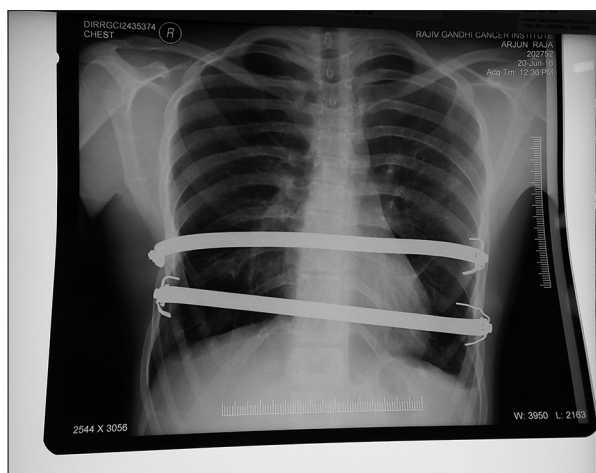


Figure 2: Chest radiograph with two pectus bars *in situ*



Figure 3: Intraoperative image of pectus bar removal

In some patients with metal allergy,^[42] a specially designed titanium pectus bar is used, which is also magnetic resonance imaging compatible. These bars need to be bent before the procedure by the manufacturing company as per the preoperative CT scan of the patient to facilitate surgical insertion.

Patient Preparation

Distance between the right and left midaxillary lines is measured before surgery. Originally, the standard length of pectus bars was 1 cm shorter than this distance, but recent studies using bars up to 3 inches shorter have drastically reduced the bar dislocation rate.^[45] Antibiotic prophylaxis beginning 1 h before surgery and continued for the next 48 h is essential.

Anesthetic Management

Preanesthetic evaluation

A thorough preanesthetic evaluation is the cornerstone of successful anesthetic management in such complex surgeries. Characteristics of associated syndromes such as marfanoid facies and high-arched palate should be noted [Table 1]. Marfans’ syndrome patients with scoliosis are at high risk for progression of the deformity to undesirable levels and they give a history of failed brace therapy.^[16] Patients with anterior chest wall deformities must be clinically and radiographically examined for signs of scoliosis.

In preoperative assessment, all routine investigations (complete blood count, coagulation profile, urine analysis, random blood sugar, renal and hepatic function tests, chest X-ray, and electrocardiogram) should be done. In addition, special investigations such as PFTs, noncontrast CT scan of the chest, and a cardiac echocardiography in patients

with Marfans’ syndrome or cardiac murmurs should be advised. Patients with a Haller index >3.2 are considered candidates for the minimally invasive repair. The PFT typically demonstrates mild changes in pulmonary volumes (restrictive pattern).^[27,29]

Positioning

The surgery is performed in supine position with both arms extended 90° to allow adequate access to the entire anterolateral chest wall.^[46] Hyperextension of the arms is avoided to prevent injury to the brachial plexus.

Trendelenburg position is attained before closure of the chest wall incisions. A combination of large tidal volumes with positive-end expiratory pressure is used to eliminate any residual pneumothorax. A temporary red rubber catheter placed through the trocar site and connected to suction or underwater seal can be used to evacuate any residual intrapleural air.^[46,47]

Anesthetic technique

The combination of general endotracheal anesthesia and a thoracic epidural (for postoperative pain relief) is considered ideal.^[48,49] Adequate oxygenation, normocarbia, and normothermia must be maintained. Invasive monitoring with placement of arterial line and central venous pressure catheter is generally not indicated, unless there are coexisting cardiopulmonary comorbidities. In one reported case, during the manipulation of the pectus bar in the anterior mediastinum, a sudden decrease in arterial pressure due to the compression of the heart occurred necessitating an intraarterial line for continuous monitoring of arterial pressure.^[50]

Induction of anesthesia should include high-dose opioids. Thoracic epidural catheter (between T4 and T12 level) can be

Table 1: Congenital syndromes associated with pectus deformity

Name of syndrome	Pectus carinatum	Pectus excavatum	Associated Symptoms
Marfan syndrome (connective tissue disorder)	Yes	Yes	Arachnodactyly, flat feet, loose joints, learning disabilities, nearsightedness, eye problems, scoliosis
Edward’s syndrome (Trisomy 18)	Yes	No	Low birth weight, mental deficiency, micrognathia, microcephaly, low-set ears, clenched hands, crossed legs, round-bottomed feet, undescended testicles, underdeveloped fingernails
Down’s syndrome (Trisomy 21)	Yes	No	Mongoloid facies, mental retardation
Homocystinuria	Yes	Yes	Flushed cheeks, knocked knees, long limbs, mental retardation, psychiatric disorders, highly arched feet
Morquio syndrome	Yes	Yes	Knock knees, widely spaced teeth, macrocephaly, loose joints, and an abnormal development of bones
Multiple lentiginos syndrome	Yes	Yes	Dark skin spots on the neck and chest area, delayed puberty, pulmonic stenosis, cryptorchidism, hypogonadism
Osteogenesis imperfecta (brittle bone disease) type-I collagen disorder	Yes	No	Multiple bone fractures, deafness, eye discolorations, loose joints, flat feet, bowed limbs, scoliosis, kyphosis

placed postinduction as pediatric patients are apprehensive and generally not very cooperative. In patients with associated scoliosis, ultrasound guidance can be utilized for accurate epidural needle and catheter placement.

Intraoperatively, the anesthesiologist should be most vigilant during the following five critical instances, which can result in increased perioperative morbidity and mortality. These include:

1. Hemodynamic instability at induction can occur due to reduction in venous return by induction agents, positive pressure ventilation, and restrictive lung pathology from deformed thoracic cage.

An unnoticed diaphragmatic injury during Nuss procedure is reported to have resulted in incarcerated diaphragmatic hernia (with the twisted stomach, transverse colon, and spleen lying in thorax). Cardiovascular collapse occurred during induction of anesthesia for hernia repair.^[51]

2. Potential for cardiac and great vessel perforation leading to massive blood loss during bar manipulation.

Cardiac perforation requiring emergency cardiopulmonary bypass in a 29-year-old male with Marfan syndrome and previous mitral valve repair undergoing a Nuss procedure for pectus excavatum is reported in literature.^[52] The ability to perform effective chest compressions in the event of cardiac arrest is also significantly hampered due to the presence of the chest wall bars.^[53] A transesophageal echocardiogram (TEE)^[54,55] may prove valuable by real time intraoperative monitoring for cardiac compression and injury.^[56]

3. Potential for malignant arrhythmias during insertion and bar fixation.

Out of 21 patients in a study, six developed sinus tachycardia and one exhibited premature atrial contraction followed by prompt spontaneous recovery at the time of bar introduction into the chest wall.^[57]

4. Consequences of bilateral iatrogenic pneumothorax before chest wall closure.

The X-ray findings in a study revealed residual pneumothorax in seven and pleural effusion in eight out of the 21 patients studied.^[57]

5. Reversal of anesthesia and awakening must be smooth with minimal cough and movement, to prevent the risk

of early bar displacement and surgical emphysema. The patient must not be extubated under lighter planes of anesthesia.^[58-61]

In earlier surgeries, one-lung ventilation was provided by the anesthesiologists for these procedures. However, recently two-lung ventilation combined with thoracoscopy (for direct visualization of mediastinal structures) has been able to provide adequate exposure and safety. Nuss procedure was performed under thoracoscopic guidance with artificial capnothorax (4 mmHg) using carbon dioxide (CO₂) by Futagawa *et al.*^[57] in 21 patients. After fascia suturing of the thoracic incisions and before removal of the thoracic trocar, the CO₂ insufflation was stopped, and the accumulated CO₂ was washed out using positive pressure ventilation. They used medical air, oxygen, sevoflurane, and fentanyl in all patients for general endotracheal anesthesia, avoiding nitrous oxide (similar to our institutional protocol). In the presence of pneumothorax, administration of 75% nitrous oxide is known to double the pneumothorax volume within 10 min and treble it within ½ h. These significant volume effects may compromise cardiorespiratory function.

Thoracic epidurals are known to cause postoperative urinary retention (incidence ranging from 31% to 69%)^[61,62] in patients undergoing thoracic surgery. Hence, retention of the Foley's catheter is recommended.

Chest radiography is performed after surgery to confirm adequate lung expansion, to visualize the final positioning of the bar, and to monitor for postoperative pneumothorax, pleural effusion, or bar displacement.

Postoperative Pain Relief

Postoperatively, close hemodynamic monitoring and aggressive intervention for hemodynamic or pulmonary deterioration and providing adequate analgesia are the major anesthetic implications. Even though this technique is minimally invasive, forceful bending of the sternum, and cartilages causes significant postoperative pain and discomfort, especially in adults with ossified cartilages. Multimodal postoperative pain relief gives the best result in these patients.^[58,59] Continuous epidural infusion of fentanyl with local anesthetics and intravenous narcotics for breakthrough pain is recommended routinely. PCA, epidural as well as intravenous are the dictum in these patients. Multimodal anesthesia with addition of methadone,^[58] paravertebral nerve blocks,^[54] and wound infusion catheters^[59] are alternatives to epidural catheters. Selective use of nonsteroidal anti-inflammatory drugs (NSAIDs) and alpha-2

agonists are other available options.^[60] Epidural catheter is retained for 72 h postoperatively. Ibuprofen (prostaglandin synthesis inhibitor) is the drug of choice for mild to moderate pain as it inhibits the inflammatory mediators.

Epidural fentanyl (3 µg/kg/h) in 0.125% bupivacaine or 0.2% ropivacaine was administered at the rate of 0.15 ml/kg/h continued into the 3rd postoperative day by Futagava *et al.*^[57] for postoperative pain relief. More than half of the patients (57.1%) required no additional analgesics. Some patients (19.0%) required a single dose of diclofenac sodium or pentazocine Weber *et al.*^[62] compared intravenous PCA with morphine with thoracic epidural analgesia (0.2% ropivacaine with 2 µg/ml fentanyl) and found epidural to provide superior analgesia in adolescents. In another study, thoracic epidural analgesia by itself provided effective analgesia in 53% of children who underwent surgical correction of pectus deformity and reduced the intravenous opioid requirement in the remaining 47% cases. No catheter-related complications were encountered. In addition, sedation and respiratory depression which plague high-dose opioid usage were circumvented.

Conflicting results regarding utility of an epidural catheter in children have been reported. In one study, out of 188 patients committed to epidurals, 65 either had a failed attempted epidural or a dysfunctional catheter within the 1st postoperative day, while those on intravenous opioid PCA had a shorter operating room as well as hospitalization time and early transition to oral medication with comparable postoperative pain relief.^[63] Another study found that pain scores favored epidurals for the first 2 days and opioid PCA thereafter^[64] while still another study found both to be equally efficacious.^[65]

Patient mobilization is initiated on the 2nd or 3rd postoperative day^[66] by flexing the bed at the hip level and keeping the back straight. The patient is instructed to avoid trunk rotation or to sit in bed with the thoracic spine flexed. The epidural catheter is generally removed on the 3rd postoperative day, and the patient should be fully ambulatory after epidural removal. Aggressive physiotherapy and early ambulation go a long way in improving cardiorespiratory function and overall patient results.

Postdischarge Instructions

The patient can be discharged home after 4–7 days, once pain is adequately controlled with oral medications. Good posture, keeping the spine straight, no slouching or bending at the hip and no lifting of heavyweights for at least a month after surgery are advocated. Physiotherapy should then be

commenced to promote healing and re-modeling of the chest wall. A direct blow to the chest as in contact sports such as wrestling or football may predispose the patient to bar displacement and such aggressive sport needs to be avoided until the bar has been removed.

Future Perspectives

The small incision sternoplasty procedure was developed in New Zealand, to improve upon the Nuss technique. It involves an average 7 cm incision and claims to rectify all forms of anterior chest wall deformity, including symmetrical and asymmetrical pectus excavatum and carinatum.

Conclusion

Nuss procedure is a minimally invasive technique in which rigid metal bars are placed transthoracically beneath the sternum and costal cartilages, until permanent remodeling of the chest wall has occurred. Intraoperative vigilance for cardiac and great vessel perforation, arrhythmias, and management of pneumothorax are essential and hence the utility of intraoperative TEE. Degree of postoperative pain, especially in adults, is severe enough to merit a thoracic epidural catheter, with concurrent use of opioids (preferably patient controlled epidural in adults and patient controlled intravenous in children) and NSAIDs. The major anesthetic goals include an extensive preanesthetic evaluation, maintenance of hemodynamic stability at critical stages, adequate pain relief, vigilant monitoring for perioperative complications, and early postoperative ambulation with physiotherapy.

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Conflicts of interest

There are no conflicts of interest.

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