

Anesthetic and Pain Management Considerations for the Nuss Procedure

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Pectus Excavatum

Pectus excavatum (PE) is a relatively common deformity of the chest wall, occurring in approximately 1 in 300 births. Although it is often referred to as a congenital abnormality, many children do not have obvious manifestations until age 1 or older. It occurs more often in males in a ratio of 4:1. In some cases there is a genetic component with some evidence of autosomal dominance with male to male transmission. Although the development of PE may be related to upper airway obstruction and/or sleep apnea (OSAS) and disorders of connective tissue such as Marfan syndrome, most patients with PE have no associated medical conditions.

Pectus excavatum has been recognized for centuries. Bauhinus described a patient in 1594 with pulmonary insufficiency (dyspnea and paroxysmal cough) associated with a severe pectus excavatum. Multiple case reports were described in the 19th century, including one by Ebstein in 1882 describing 4 patients. Treatment consisted of “fresh air, breathing exercises, aerobic activities, and lateral pressure.” Thoracic surgical approaches were developed in the early part of the 20th century, but it wasn’t until mid-century that Ravitch reported the technique which became the standard prior to the advent of the Nuss procedure. The Ravitch operation involved a mobilization of the sternum by resection of the costal cartilages bilaterally and sternal osteotomy. A modification involving the placement of a bar through the distal end of the sternum was reported in 1956 by Wallgren and Sulamaa which prevented the recurrence of the deformity. Further modification by Adkins and Blades in 1961 used a similar bar behind instead of through the sternum. Concern about cartilage resection resulting in inflexibility of the chest wall (“acquired asphyxiating chondrodystrophy”) resulted in further modifications in which the costal cartilage was cut but not completely removed. Nevertheless, concerns about occurrence of this condition with advancing age after repair in childhood led to a decreased number of operations performed on young children, deferring the surgery until adolescence, at which time surgical results were less satisfactory due less flexibility of the chest wall.

In the late 1980’s Donald Nuss began to develop the Nuss procedure, which is a minimally invasive technique for placing a convex bar under the sternum with no resection or cutting of the costal cartilages. Dr. Nuss reasoned that since the cartilages were so malleable and the chest wall relatively flexible, especially in young children, the bar would allow the chest wall to change its configuration without invasive methods. In 1998, Nuss and colleagues reported their 10 year experience with the Nuss procedure in 148 patients.(1) Over the past 7 years, Nuss and other groups have continued to make modifications to the technique, which now most commonly is performed with thoracoscopic assistance for accurate, safe placement of the substernal bar.(2) The length of surgery has been significantly shortened with the advent of the Nuss procedure when compared to the Ravitch procedure (67 minutes vs 197 minutes).

In the early years, the procedure was most commonly performed in younger children, with a median age of 5 years. Although the original theory related to the malleability of the younger child’s chest wall, the procedure has been found to have good results in older children and young adults and recent series reported have had a median age of 12.4 years. Some groups have reported the use of the procedure in adults. (3) Although this extension to older patients has been successful surgically, modification of postoperative analgesic regimen has been required because of increased severity and duration of pain in the older patient population.

Indications for repair of pectus excavatum and preoperative considerations

The indications for which pectus excavatum is repaired are related to the severity of the deformity. Many regarded repair as necessary for cosmetic rather than functional reasons because early studies after the Ravitch procedure did not demonstrate improvement in cardiopulmonary function (4), and some even showed a decrease in lung capacity, possibly due to increased rigidity of the chest wall.

Young children with minimal deformities are asymptomatic and do not require operation. The deformity frequently increases with growth and symptoms may develop as the chest wall loses the flexibility of the young child. Cardiac function at rest is usually normal, but cardiac output during exercise may be restricted due to sternal compression and displacement of the heart. Stroke volume (SV) decreases by 40% in the upright vs the supine position, while no change occurs in normal controls (5). With exercise, SV increases to a lesser extent in patients with PE than in normal controls, and is fixed with increasing work, requiring an increase in heart rate to meet demand for increased cardiac output. Right ventricular emptying is reduced compared to normal controls. (6) These symptoms may increase in adolescence with development of decreased exercise tolerance, dyspnea, and tachycardia. Adolescent boys with pectus excavatum have been shown to have lower measures of cardiorespiratory fitness than a group of age-matched controls.(7) After pectus repair the cardiac index in the upright position increases to a more normal value with a smaller difference from supine (8 and exercise tolerance improves.

Aside from chest x-ray, CT scan is the most frequent study performed preoperatively in patients with PE. The anterior posterior distance from the sternum to the spine at the point of maximal incurving and the transverse dimension of the chest are measured. The ratio between the transverse chest and sternal-vertebral distances is calculated (Haller index).(9) The median normal value for the index is 2.56. An index > 3.25 has become the standard indication for surgery.

Although there is cardiac compression with severe deformities, echocardiography is not always performed in the absence of symptoms such as irregular rhythm or palpitations. Cardiac auscultation may reveal a murmur which may result from compression of the pulmonary outflow tract. There may also be a click if mitral valve prolapse (MVP) is present. MVP may resolve after PE repair. Echocardiography may be performed to ascertain the presence of MVP.

Pulmonary function may be diminished in patients with moderate to severe PE. Abnormalities may include restrictive pattern on spirometry (10) and ventilation-perfusion abnormalities (11). Ventilatory and cardiovascular responses to exercise have been shown to be abnormal, even in patients who had regular aerobic exercise (12). Compression of the left lung is observed due to displacement of the heart into the left chest with retention of radionuclide in the left lung. Recently a new radionuclide technique (Tc-99m MAA SPECT) has been shown to demonstrate an increase in lung volume of from 9 – 23%, more marked on the left, in 3 patients studied (13). When pre- and postoperative pulmonary functions were compared with the Ravitch operation, there was improvement only in those patients with the most severe defects, and some patients with moderate defects actually had reduced pulmonary function (increased restrictive component) after costochondrectomy (14). The Nuss procedure, by eliminating costochondrectomy and retaining elasticity of the chest wall and potential for chest wall growth, is unlikely to have such adverse effects on pulmonary function, a result confirmed in a small number of patients in two recent studies (15,16). Because the abnormalities described have no impact on anesthetic management, preoperative pulmonary function tests are not recommended for patients scheduled for Nuss procedure.

Preoperative testing continues to include CT and echocardiogram for good patient assessment, but also because most payers require a Haller index of > 3.25 or evidence of cardiac abnormalities for the procedure to be covered.

Anesthetic management of patients for Nuss procedure

Reports of outcome of the Nuss procedure in the surgical literature have had only brief discussion of anesthetic management, usually stating that intraoperative management consisted of a combination of general and thoracic epidural anesthesia and that postoperative pain was managed with epidural infusion, usually of bupivacaine and an opioid (fentanyl, morphine or hydromorphone). The reality of postoperative pain management of patients after the Nuss procedure has proved to be less straightforward.

In the early days of the development of the Nuss procedure, the operation was performed with general anesthesia only, but in Nuss et al's 1998 report, it was stated that in the final 5 patients of the series, epidural catheters had been placed to be used for postoperative pain control. Pediatric surgeons widely requested the placement of epidural catheters and it was felt that excellent epidural analgesia was essential for optimal recovery from surgery.

In adolescents, epidural placement may be done with moderate IV sedation prior to induction of anesthesia. Placing the catheter with sedation prior to induction allows assessment of the onset of the block, but many practitioners do not wait to assess before induction. In younger children, the epidural may be placed after induction of general anesthesia. The needle may be placed anywhere from T 6-7 to T10-11, but the goal should be to locate the catheter tip in the region of T5-7. Placing the tip of the catheter in close proximity to the spinal dermatome affected by the surgery allows excellent analgesia to be achieved with smaller infusion volumes. After a test dose (3 mL of lidocaine 1.5% with 1:200k epinephrine), the catheter is dosed with local anesthetic +/- opioid. Some practitioners supplement the epidural intraoperatively with bolus administration of 60% of the original bolus every 90 minutes, while others start the infusion in the OR after the bolus is administered. After epidural bolus administration, it is common for the heart rate to decrease, especially in adolescents. The blood pressure may decrease by 10 – 20% and may require fluid administration.

Anesthesia induction may be by inhalation or intravenous, non-depolarizing muscle relaxant is administered, after which an endotracheal tube is placed. General anesthesia is maintained with vapor anesthetic (sevo-, des-, or isoflurane) in air-oxygen mixture. Nitrous oxide is avoided because of the risk of pneumothorax. After induction, most surgeons place a foley catheter, which is maintained until the epidural is discontinued. It is not clear, however, that a urinary catheter is needed with a segmental thoracic block as bladder control should be maintained. Epidural opioids can cause urinary retention, but intravenous opioids may as well

Although early reports of the Nuss procedure described the use of single lung ventilation, the current use of unilateral CO₂ insufflation is sufficient to optimize visualization.

Positioning concerns

As the Nuss bar is placed through the left sided incision in the lateral chest wall at the level of the maximum sternal displacement, abduction of the arms is necessary for access by the surgeon. For maximal access, the left arm especially has been abducted greater than 90°, which has resulted in anecdotal reports of brachial plexus injury following the procedure, usually transient. Some surgeons may increase the risk of this complication by placing a vertical roll between the scapulae to push the chest forward. This complication has not been discussed in the surgical literature. Recently, Fox et al have suggested a positioning strategy for the left arm using an arthroscopy sling which appears to reduce the incidence of brachial plexus injury (17).

Intraoperative complications

Serious complications have occurred intraoperatively during the Nuss procedure, including pneumothorax, hemothorax, right ventricular puncture, arrhythmia, and decreased blood pressure due to cardiac compression. In the immediate postoperative period, mediastinal and subcutaneous emphysema have been reported (1, 18). Although some of these complications may be life-threatening, they are exceedingly rare. Although some authors have arterial line placement, it is not necessary when the procedure is done by an experienced surgeon, and the bar placed with the aid of thoracoscopy. A chest x-ray should be performed at the end of surgery in the operating room to evaluate for the presence of

pneumothorax, hemothorax, or mediastinal emphysema. Small pneumothoraces after thoracoscopy in surgical case series have been very common (52%) and the majority resolve spontaneously (1). Some surgeons have reduced the incidence of pneumothorax by leaving a tube in the chest until the lateral incisions are closed. The patient is placed in Trendelenburg and positive pressure ventilation with 5 cm PEEP applied with the end of the tube under water seal. The tube is removed with inspiratory hold when no further bubbles escape.

Postoperative pain management

Careful attention to the adequacy of the block is essential on emergence from anesthesia. If the infusion was not started in the OR, it should be started promptly in the PACU. Examination should be performed using a cold stimulus to verify the extent and bilaterality of the block. Many of these patients, especially the adolescents, have a great deal of anxiety and may benefit from sedation with a benzodiazepine (diazepam or lorazepam) in the early postoperative period. Postoperatively, patients may be tachypneic due to anxiety, but it is important to remember that pneumothorax may increase and hemothorax may occur. There should be a low threshold for obtaining a chest x-ray in the postoperative period.

In reality, there is no data comparing continuous epidural analgesia (CEA) alone versus intravenous opioids (IVPCA) after the Nuss procedure, although a benefit has been demonstrated in adults having other types of open thoracotomy (19). Although one case series has been reported, the epidural dosing (volume, local anesthetic, opioid) were not standardized and the proportion who had excellent pain relief was not encouraging (53%) (20). Scheit et al. presented a case series at the 2005 ASA meeting in which 33 adolescents received CEA at 6-9 mL/h with the authors’ reporting excellent pain relief in those whose catheters were retained (21). This group kept the epidurals in for longer (5+-2 days) than is usual in the US. The epidural infusion mixtures which have been used for thoracic analgesia in children are listed in Table 1. The addition of clonidine to the epidural infusion is felt by many practitioners to improve analgesia and reduce opioid side effects such as pruritus and nausea. A recently completed study may provide some evidence for this belief (22).

Table 1. Dosing regimens for perioperative epidural analgesia

Weight (kg)	<u>Intraoperative dose</u>		<u>Postoperative infusion</u>	
	LA	Opioid	LA	Opioid
30-50	Bupiv 0.25%	Fentanyl 1 µg/kg Hydromor 7-8 µg/kg	Bupiv 0.1% or Ropiv 0.2%	Fentanyl 2.5*-5 µg/mL or Hydromor 3* – 5 µg/mL or Morphine 25*-50 µg/mL
> 50	Bupiv 0.25%-0.5% or Lido 1.5-2.0%	Same as 30-50 kg		

Bupiv = Bupivacaine; Lido = Lidocaine, Ropiv = Ropivacaine; Hydromor = Hydromorphone

* if clonidine is used, the lower concentration of opioid is used

** if catheter tip is low thoracic or lumbar, higher infusion volumes may be needed

§ If PCEA is desired, continuous rate is reduced to 0.2 mL/kg/hr (maximum 10 mL/hr) with 1-2 boluses of 2-3 mL (lockout 15 – 30 minutes)

Recent surgical reports and the website of Dr. Nuss' institution, seem to indicate that many patients, especially those in the older age groups, are receiving IVPCA to supplement epidural infusion (23), and that even with this supplementation, the transition from epidural to oral analgesics can be problematic. These groups frequently use local anesthetic +/- clonidine in the epidural infusion and use concomitant IVPCA. Ong et al. leave the epidural in 3-5 days and continue the IVPCA for one day longer to ease this transition (23). Length of stay varies greatly, with duration of 7 days common in Europe and Australia. In the United States, 5 days is much more common, with the epidural being removed on day 3 or 4. Some patients appear to have a significant component of muscle spasm and resulting pain. Others may have significant anxiety related to perception of inability to take a deep breath. Both of these groups of patients may benefit from a small dose of diazepam (2 mg q6h orally). In some cases, patients may benefit from continuing diazepam after discharge. Muscle spasm has even been reported to result in the development of an acute scoliosis postoperatively (24). Opioid side effects should be anticipated, whether opioids are administered epidurally or intravenously.

On the day the epidural (or IVPCA) is to be discontinued, ketorolac is started, which helps to smooth the transition. Oral analgesics (oxycodone or hydrocodone, acetaminophen) are administered around the clock. The duration of pain after discharge can be quite prolonged and exceeds what was seen after the Ravitch operation (24). Discharge medications usually include an opioid, NSAID (ibuprofen), and possible a benzodiazepine. Continued opioid administration may be required for 4 – 6 weeks after discharge. Patients may require opioid weaning when pain resolves because of the duration of treatment.

Conclusion

Perioperative anesthetic and pain management of patients undergoing the Nuss procedure is a challenge to the anesthesiologist. Although there are cardiorespiratory abnormalities associated with PE, these rarely impact anesthetic management or increase risk. The procedure may be associated with serious intraoperative complications, which require vigilance on the part of both the surgeon and anesthesiologist. Patients and their families (and surgeons) have high expectations of the efficacy of epidural analgesia to provide a pain-free postoperative recovery. These expectations are heightened by widespread access to "information" on the web (26). Surgeons are beginning to recognize that the postoperative pain management of these patients may be complex, requiring multi-modal therapy and carefully managed transition from epidural to oral analgesia. Patients may require long-term pain management after discharge and anesthesiologists may be asked to help surgeons with the outpatient pain management of these patients.

References

1. Nuss D, Kelly RE Jr., Croitoru DP et al. A 10-year review of a minimally invasive technique for the correction of pectus excavatum. *J. Pediatr Surg* 33:545-552, 1998
2. Croitoru DP, Kelly RE Jr, Goretsky MJ, et al. Experience and modification update for the minimally invasive Nuss technique for pectus excavatum repair in 303 patients. *J Pediatr Surg* 37:437-445, 2002
3. Coln D, Gunning T, Ramsay M, et al. Early experience with the Nuss minimally invasive correction of pectus excavatum in adults. *World J Surg* 26:1217-1222, 2002
4. Wynn SR, Driscoll DJ, Ostrom NK et al. Exercise cardiorespiratory function in adolescents with pectus excavatum: Observations before and after operation. *J Thorac Cardiovasc Surg* 99:41-7, 1990
5. Beiser GD, Epstein SE, Stampfer M et al. Impairment of cardiac function in patients with pectus excavatum, with improvement after operative correction. *N Engl J Med* 287:267-72, 1972
6. Mocchegian R, Badano L, Lestuzzi C et al. Relation of right ventricular morphology and function in pectus excavatum to the severity of the chest wall deformity. *Am J Cardiol* 76:941-6, 1995
7. Rowland T, Moriarty K, Banever G. Effect of pectus excavatum deformity on cardiorespiratory fitness in adolescent boys. *Arch Pediatr Adolesc Med* 159:1069-1073, 2005

8. Kowalewski J, Barcikowski S, Brocki M. Cardiorespiratory function before and after operation for pectus excavatum: medium-term results. *Eur J Cardiothorac Surg* 13:275-9, 1998
9. Haller JA Jr, Kramer SS, Lietman SA. Use of CT scans for selection of patients for pectus excavatum surgery: a preliminary report. *J Pediatr Surg* 22:904-6, 1987
10. Cahill JL, Lees GM, Robertson HT. A summary of preoperative and postoperative cardiorespiratory performance in patients undergoing pectus excavatum and carinatum repair. *J Pediatr Surg* 19:430-3, 1984
11. Blickman JG, Rosen PR, Welch KJ et al. Pectus excavatum in children: pulmonary scintigraphy before and after corrective surgery. *Radiology* 156:781-2, 1985
12. Malek MH, Fonkalsrud EW, Cooper CB. Ventilatory and cardiovascular responses to exercise in patients with pectus excavatum. *Chest* 124:870-82, 2003
13. Kinuya K, Ueno T, Kobayashi T et al. Tc-99m MAA SPECT in pectus excavatum: assessment of perfusion volume changes after correction by the Nuss procedure. *Clin Nucl Med* 30:779-82, 2005
14. Derveaux L, Clarysse I, Ivanoff I, et al. Preoperative and postoperative abnormalities in chest x-ray indices and in lung function in pectus deformities. *Chest* 95:850-6, 1989
15. Borowitz D, Cerny F, Zallen G, et al. Pulmonary function and exercise response in patients with pectus excavatum after Nuss repair. *J Pediatr Surg* 38:544-7, 2003
16. Sigalet DL, Montgomery M, Harder J. Cardiopulmonary effects of closed repair of pectus excavatum. *J Pediatr Surg* 38:380-5, 2003
17. Fox ME, Bensard DD, Roaten JB et al. Positioning for the Nuss procedure: avoiding brachial plexus injury. *Pediatric Anesthesia* 15:1067-71, 2005
18. Hebra A, Swoveland B, Egbert M, et al. Outcome analysis of minimally invasive repair of pectus excavatum: review of 251 cases. *J Pediatr Surg* 35:252-258, 2000
19. Senturk M, Ozcan PE, Talu GK, et al. The effects of three different analgesia techniques on long-term postthoracotomy pain. *Anesth Analg* 94:11-5, 2002
20. McBride WJ, Dicker R, Abajian JC et al. Continuous thoracic epidural infusions for postoperative analgesia after pectus deformity repair. *J Pediatr Surg* 31:105-7, 1996
21. Scheit MW, Litz RJ, Gaebler R, et al. Postoperative thoracic epidural analgesia in young adolescents undergoing Nuss' procedure for pectus excavatum repair. *Anesthesiology* 103:A1387, 2005
22. Cucchiario G, Adzick SN, Rose JB et al. A comparison of epidural bupivacaine-fentanyl and bupivacaine-clonidine in children undergoing Nuss procedure. *Anesth Analg* 2006 (in press)
23. Ong CCP, Choo K, Morreau P, et al. The learning curve in learning the curve: a review of Nuss procedure in teenagers. *ANZ J Surg* 75:421-4, 2005
24. Niedbala A, Adams M, Boswell WC, et al. Acquired thoracic scoliosis following minimally invasive repair of pectus excavatum. *Am Surg* 69:530-3, 2003
25. Fonkalsrud EW, Beaney S, Hebra A, et al. Comparison of minimally invasive and modified Ravitch pectus excavatum repair. *J Pediatr Surg* 37:413-7, 2002
26. www.pectusinfo.com/hospital.htm