Pectus excavatum is the number one birth defect in males\(^1\). It can be corrected by two very different types of surgical procedures: the Nuss and the Ravitch procedure. According to Keri Ann Smith R.N. more than 92% of the patients suffering from pectus excavatum are unaware that they even have a birth defect that could be affecting their health\(^2\). The Ravitch procedure has been used to repair this birth defect for many years, however the Nuss procedure is beginning to gain acceptance. The Nuss procedure has been performed for less than 12 years. In medical terms this is considered still experimental due to the short amount of time the procedure has been performed\(^2\). The majority of people suffering from pectus excavatum experience no symptoms associated with the birth defect and correction is sometimes considered cosmetic by health insurance plans\(^2\).

As stated by Kerri Ann Smith R.N., more than 92% of patients suffering from pectus excavatum are unaware that they even have a birth defect that could be affecting their health. From this statement you could assume that this is one of the most hidden birth defects facing society. As a result of this we need to raise awareness of what pectus excavatum actually is, and what you can do about it. Ultimately this research will serve as a model to educate potential patients suffering from pectus excavatum.

I will be evaluating the two surgical procedures used to repair pectus excavatum to determine which procedure is a more successful surgery. What is a successful surgery? Well according to Dr. Cohn, who is a leading pectus excavatum repair surgeon\(^3\), “Success of a pectus excavatum operation is based on relief of cardiac compression resulting in relief of symptoms and increased energy levels, adequate pain management, length of hospital stay, time to return to normal activity, duration of daily medication, and physical appearance.” Before I begin to evaluate the procedures I will be giving you an overview of what pectus excavatum is, diagnosis associated with pectus excavatum, the Nuss procedure, and the Ravitch procedure.

I believe that the results from the Nuss procedure far outweigh those of the Ravitch. Even though the Ravitch procedure is performed more now I believe all of this will change in the near future. The Nuss procedure offers substantial benefits in the areas of relieving pectus excavatum symptoms, operative, and postoperative care. The Nuss procedure will make the Ravitch procedure obsolete.

What is Pectus Excavatum?

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Pectus excavatum is a chest wall abnormality where the sternum (breast bone) and ribs are depressed inwards (concave) giving the appearance of a sunken chest. Pectus excavatum happens to also be one of the most common chest wall birth defects, some 1 out 8 are born with this birth defect. This sunken chest appearance is often recognized at or shortly after birth (congenital) or may be acquired at a later time. According to Dr. Cohn, “The child may also have rounded shoulders with their abdomen protruding outwardly or a “pot belly” appearance as a result of the rib cage sticking out.” A pectus excavatum may be caused by an excessive overgrowth of costal (rib) cartilage, low bone densities, poor nutrition and muscle imbalances. It is found more often in boys than girls. Pectus excavatum becomes more noticeable once the child enters periods of rapid growth such as during early adolescence. It is not uncommon for a child with a pectus excavatum to also have curvature of the spine (scoliosis), a hunched over posture (kyphosis) or Vitamin D deficiency (rickets). In addition to the unattractive cosmetic appearance, pectus excavatum displaces the heart into the left chest to varying degrees depending on the severity of the deformity. Compression of the heart will reduce the stroke volume and cardiac output in moderate to severe deformities and thus cause more rapid fatigue than in a person with a normal chest.

The heart usually compensates by having a much faster beat (tachycardia) when the person exercises. The sternal depressions also decrease the cavity in which the heart and lungs lie (thoracic volume), which reduces the amount of air entering and leaving the lung with each respiratory motion. The body often compensates by developing more shallow and rapid respirations, and by having wider movements of the diaphragm when the patient is physically active. Patients thus experience shortness of breath and a considerable decrease in stamina and endurance during exercise. Many persons will experience a compression-type pain and discomfort in the lower chest. Along with these physical signs there are a few physical and psychological symptoms. Physical symptoms associated with pectus excavatum include chest pain, respiratory complications, and a lack of stamina. Psychological symptoms also overlooked range from mild self-conscious behavior, loss of motivation, anxiety, and other social problems.

**Should You Be Concerned?**

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It is easy to see what a pectus excavatum looks like from the outside. However, you need to know whether the pectus excavatum is causing problems on the inside. One of the main functions of the rib cage is to “protect” the lungs and heart\textsuperscript{11}. In people with a pectus excavatum, the rib cage is shaped differently. Although the heart and lungs are still protected by the ribs, the concave shape of the rib cage may cause these vital organs to be compressed\textsuperscript{1}. The chest wall may restrict the lungs from expanding properly interfering with optimal lung growth. This restriction may prevent normal contractions leading to cardiac limitations. Depending on the severity of the chest wall abnormality, the patient may experience restricted function of the heart and lungs. This may become apparent during times of physical activity when the child may have decreased endurance and stamina\textsuperscript{12}. Some individuals may experience chest pain, cough, wheezing and recurrent respiratory infection. Dr. Cohn says, “In addition to bony abnormalities and possible lung and heart restriction, these patients often become very self-conscious about appearance which may impact their lifestyle choices.”

**Diagnosis**

When the classic signs and symptoms are present, consultation with a medical team that specializes in the care of children with pectus excavatum is suggested\textsuperscript{13}. This team should include a pulmonologist who specializes in determining the significance of the chest wall compression on the lungs and heart; a physical therapist who can address the consequences of the chest wall abnormality; and a pediatric surgeon who can offer surgical intervention if required\textsuperscript{3}. Proper assessment of this condition includes the following\textsuperscript{3}:

- A chest x-ray from the front and side view will demonstrate the severity of the deformity and permit calculation of the pectus severity index;
- A CT (computerized tomography) scan of the chest provides slightly more information and is more accurate in determining the severity index (Figure 3 & 4);
- An EKG and ECHO (picture of the heart) study are helpful if a heart murmur, or known heart disease are present;
- Pulmonary function (exercise) tests during exercise to determine how the heart and lungs respond to physical stress (Figure 5).


Treatment Options

Treatment may include non-invasive physical retraining and realignment physical therapy, invasive surgery, or both. Aggressive physical therapy may have a role in slowing the progression of the chest wall abnormality and may even reverse some of the cosmetic appearance. Consultation with an experienced physical therapist with expertise in respiratory disorders can assist you in this non-invasive approach\(^\text{14}\).

When Is Surgery Necessary?

Surgery is necessary for many patients with pectus excavatum because the chest deformity can be putting pressure on several of your vital organs. The deformity often compresses the heart and displaces it to a place where there is minimal room\(^\text{15}\). The concavity also restricts the expansion and growth of your lungs. Once it is determined that the pectus excavatum is compromising either the heart or lung, surgery is strongly recommended\(^\text{2}\).

What are my options?

The three options for surgical repair are the Nuss, Ravitch procedures, and use of silicone implants\(^\text{16}\). I did not include the silicone implant procedure in this research, because there are an extremely small number of patients that have had this procedure performed\(^\text{3}\). Also, I am looking at the repair of pectus excavatum, and the silicone implant procedure is purely cosmetic and offers no medical improvements\(^\text{3}\).

Ravitch Procedure

The Ravitch procedure is the most commonly used method although the Nuss is becoming more popular\(^\text{17}\). The Ravitch procedure consists of lifting up the chest muscles, cutting the abnormal cartilage, rotating the sternum to lie flat and inserting a bar inside\(^\text{4}\).

For this operation, a curvilinear incision is made midway between the nipples (Figure 6). Short skin flaps are then elevated. The pectoral muscles and the abdominal muscles are mobilized to expose the deformed cartilage. Short segments of cartilage are then cut from each of the deformed ribs. A thin stainless-steel bar (Adkins strut) is then placed across the lower chest of the sternum. The thin stainless-steel bar is then used to elevate the sternum as well as the chest to the desired level (Figure 7). The strut is attached to the appropriate rib on each side with fine wire. Finely minced fragments of cartilage, which have been removed earlier, are then placed into the wound to enhance cartilage regeneration.

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The pectoral and abdominal muscles are then sutured together over the cartilage repair. The skin is then closed with absorbable sutures. The thin stainless-steel bar will be left in permanently\(^\text{18}\).

The Ravitch procedure is far more invasive than the Nuss procedure. The more invasive a surgery is, the harder it is for your body to recover\(^1\). The Ravitch procedure is so invasive because it involves cutting and reshaping cartilage, breastbone, and ribs\(^1\). Also, in the Ravitch procedure the thin stainless steel bar is left in permanently. This can cause long-term problems. It has been proven to inhibit chest growth and also greatly decreases the flexibility of your chest, due to the permanent stainless steel bar\(^1\). Patients have also been very displeased with the cosmetically unpleasing scar in the middle of their chest (Figure 8 & 9).

**Nuss Procedure**

In 1998 Nuss described an innovative procedure for repair of pectus excavatum\(^19\). The Nuss procedure is a newer and minimally invasive surgery. The results associated with the procedure have been good to excellent in 94% of patients\(^2\). The procedure is gaining acceptance for correction of pectus excavatum\(^20\). Prior to surgery, a stainless steel bar (Walter Lorenz Surgical, Jacksonville, Fla.) is bent to conform to the contour of the patient’s chest at the level of the deepest part of the excavatum (Figure 10). The bar is selected so that its length is sufficient to extend from one side of the patient’s chest to the other side\(^2\).

For the operation, incisions are made on the sides of the chest. Large pockets are created to accommodate the bar. A Kelly or Crawford clamp is inserted through the openings and passed directly behind the sternum (Figure 11). The electrocardiogram is monitored for arrhythmias during passage of the clamp. An umbilical tape is then tied to the bar, and the bar is then guided across the underside of the sternum. The convex side of the bar faces down as it traverses the underside of the sternum (Figure 12, top). The bar is then rotated 180° with a vise grip or rotational device so that the convex surface elevates the sternum (Figure 12, bottom). If the correction is deemed unsatisfactory, the bar is turned over, removed from the chest, and bent further so that an appropriate correction of the deformity can be achieved. In some cases, a second bar is necessary for satisfactory correction. A cross bar is inserted in one end of the bar for stabilization (Figure 13). The convex bar and stabilizing bars are firmly sutured to the chest wall. The surgical wounds are then closed in layers. After two years when the desired shape of the chest has formed, the bar is then removed\(^2\).

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The Nuss procedure cuts operating times in half compared to the Ravitch procedure. This is always beneficial due to the high occurrence rate of something going wrong while under anesthesia\textsuperscript{21}. Since the Nuss procedure is less invasive it drastically reduces recovery time. Since the stainless steel bar used to support the chest wall is removed after a few years, the chest wall can continue to grow and allows for flexibility, unlike the Ravitch procedure. The Nuss procedure has a very high success rate of relieving the symptoms associated with pectus excavatum\textsuperscript{1}.

The technique described by Nuss offers an alternative treatment for pectus excavatum. The simplicity of the operation, the short operating time, subsequent remodeling of the chest, preservation of the chest wall growth, and avoidance of a cosmetically displeasing scar (Figure 14 & 15) have resulted in surgical treatment being sought for a deformity that has significant physiologic consequences\textsuperscript{22}.

**Methods and Procedures**

Between April 1998 and January 2001, twenty four patients, 19 to 46 years of age, were seen for pectus excavatum. Only eight patients were selected to receive surgical correction. The minimally invasive Nuss procedure was offered to four patients, while the other four patients received the Ravitch procedure. There were five men and three women. The patients had symptoms limiting lifestyle, a chest wall index greater than 3.25, and cardiac abnormality on echocardiogram. Chest wall index was determined from a computed tomography (CT) scan image of the chest comparing the dimensions of the chest. A chest wall index greater than 3.25 was determined at the Johns Hopkins Hospital to be an indication for surgery\textsuperscript{23}. The chest wall index numbers correlate with vital capacity and lung capacity.

An echocardiogram was performed on all patients at rest, and with exercise, if necessary, to document cardiac compression causing structural changes in the heart. Five men and three women, ages 19 to 32 years (mean 24 years), whose chest wall indices were 3.57 to 8.5 (mean 4.71) had the procedures. Cardiac abnormalities were present in all of the patients (Table 1).

The following data were collected on each patient: operating time, duration of epidural infusion, postoperative pain scores, length of hospital stay, alleviation of symptoms, and relief of cardiac abnormality on postoperative echocardiogram, time to return to normal activity, duration of pain medication post-hospitalization, complications, and physical scar appearance.

Table 1 - Patient Information

<table>
<thead>
<tr>
<th>Age/Sex</th>
<th>Symptoms</th>
<th>Chest Index</th>
<th>Echocardiogram</th>
<th>Date of Surgery</th>
<th>Date Bar Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>20/M</td>
<td>Exercise tolerance, Fatigue</td>
<td>4.2</td>
<td>Cardiac Compression</td>
<td>7/98</td>
<td>6/00</td>
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<tr>
<td>19/M</td>
<td>+Heart rate</td>
<td>4.6</td>
<td>Mitral valve prolapse</td>
<td>8/98</td>
<td>5/00</td>
</tr>
<tr>
<td>20/M</td>
<td>Exercise tolerance, Fatigue</td>
<td>4.24</td>
<td>Cardiac compression</td>
<td>12/98</td>
<td>12/00</td>
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<tr>
<td>21/F</td>
<td>Fainting, Exercise tolerance</td>
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<td>Compression of ventricle and atrium</td>
<td>9/99</td>
<td>NA</td>
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<tr>
<td>20/F</td>
<td>Swollen ankles, Fainting</td>
<td>5.2</td>
<td>Compression of right ventricle</td>
<td>1/00</td>
<td>7/01</td>
</tr>
<tr>
<td>32/M</td>
<td>Exercise tolerance, Fatigue</td>
<td>3.32</td>
<td>Mitral valve prolapse</td>
<td>11/00</td>
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</tr>
<tr>
<td>32/M</td>
<td>Fatigue, +Heart rate</td>
<td>3.57</td>
<td>Cardiac compression</td>
<td>1/01</td>
<td>NA</td>
</tr>
</tbody>
</table>

Note: Nuss / Ravitch

Results

Nuss: Operating time ranged from 1 to 2:05 hours (mean 1:32 hours). Daily average postoperative pain scores on a scale of 0 to 10 were 1.6 to 3.7, the highest being on the day following surgery. Lowest and highest individual scores by day were: 0 to 7 on day one, 1 to 8 on day two, 0 to 7 on day three, 0 to 4 on day four, and 2 to 4 on day five. Average daily pain scores for hospitalized patients are given in Figure 18.

Epidural catheter administration of medication for pain control was continued for 2 to 4 days (mean 2.8 days). Hospital stay was 3 to 5 days (mean 4 days). All patients had relief of cardiac compression, and one patient who preoperatively had severe mitral valve prolapse had minimal mitral valve prolapse immediately following surgery.24

All patients returned to work on normal activity between 2 and 4 weeks (mean 2.3 weeks) and to unrestricted activity by 6 weeks. Three patients stopped daily oral pain medication between 2 and 4 weeks. Pain medication was continued by 1 patient for 2 months. There were no complications associated with the Nuss procedure.1

Ravitch: Operating time ranged from 2 to 4:33 hours (mean 3:10). Daily average postoperative pain scores on a scale of 0 to 10 were 1.2 to 2.0, the highest being on the day following surgery. No epidural catheter administration of medication is needed for pain control. Hospital stay was 2 to 5 days (mean 3 days). Three patients experienced relief of cardiac compression; however one patient still had signs of pulmonary compression.25

All patients returned to work on normal activity between 1-2 weeks (mean 2.5 weeks) and to unrestricted activity in 10 weeks due to the instability of your chest wall.1 Pain medication was continued for 2 to 3 weeks (mean 2.8 weeks). All four patients suffer some sort of complication associated with the Ravitch procedure. Two patients suffered from atelectasis (collapsed lung), and urinary retention in two other patients. One late complication occurred related to the permanent stainless steel bar. The stainless steel bar separated from patient who was playing basketball 7 months after

surgery. The stabilizing bar was reattached with wire as a day surgery procedure.

The Nuss procedure technically is a more painful operation than the Ravitch procedure; however as long as you are on a well planned out pain medication schedule, pain levels are comfortable.

<table>
<thead>
<tr>
<th></th>
<th>Nuss Procedure</th>
<th>Ravitch Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Time hrs</td>
<td>1 to 2:05 (mean 1:32)</td>
<td>2 to 4:33 (mean 3:10)</td>
</tr>
<tr>
<td>Blood Loss mL</td>
<td>10 to 120 (mean 90)</td>
<td>15 to 400 (mean 250)</td>
</tr>
<tr>
<td>Hospital stay</td>
<td>3 to 5 days (mean 4)</td>
<td>2 to 5 days (mean 3)</td>
</tr>
<tr>
<td>Epidural Used</td>
<td>4</td>
<td>NA</td>
</tr>
<tr>
<td>Patients placed in ICU</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Relief of symptoms</td>
<td>100%</td>
<td>75%</td>
</tr>
<tr>
<td>Return to normal activity</td>
<td>2 to 4 weeks (mean 2.3)</td>
<td>1 – 2 weeks (mean 1.5)</td>
</tr>
<tr>
<td>Duration of Pain Medication</td>
<td>2 to 16 weeks (mean 5.5)</td>
<td>2 to 3 weeks (mean 2.8)</td>
</tr>
<tr>
<td>Complications</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Time to bar removal</td>
<td>24 months (mean 22)</td>
<td>NA</td>
</tr>
</tbody>
</table>

Note: Out of 8 patients

In conclusion the Nuss procedure clearly is more beneficial and effective than the older, more invasive Ravitch procedure. The Nuss procedure offers many benefits such as: reduced operating time, effectively stabilizes the chest, vastly reduces scarring, maintains chest elasticity, does not inhibit chest growth, drastically reduces blood loss, and creates more space for compressed vital organs. I believe more research needs to be conducted on how long the stainless steel bar (Walter Lorenz Surgical, Jacksonville, Fla.) actually needs to stay in patients that have had the Nuss procedure performed. As it stands right now, the average time the stainless steel bar is left in is around 18-24 months after the initial surgery. This time frame has proven effective, but there is speculation about how long it actually takes your chest wall to achieve structural stability after the bar has been inserted.

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References


