Effect of the Nuss Procedure on the Physical Development of Patients with Pectus Excavatum

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Purpose: This study assessed physical development of patients with pectus excavatum and evaluated the effect of the Nuss procedure on physical development.

Methods: A total of 146 patients underwent the Nuss procedure; of these, at the time of the study, the bar had been removed from 123 patients (84.9%; male 93, female 30) who were eligible for participation in this study. Heights and body weights of patients were measured prior to surgery and immediately before bar removal. Chest computed tomography (CT) was performed preoperatively and immediately before bar removal. The associations between physical development and chest CT indices were evaluated.

Results: The height standard deviation score (SDS) was −0.66 ± 2.23 preoperatively and 0.04 ± 1.34 immediately before bar removal (p < 0.01). The weight SDS was −0.02 ± 2.59 preoperatively; it increased significantly to 0.56 ± 1.56 immediately before bar removal (p < 0.01). The Haller index (3.85 ± 1.18 to 2.99 ± 0.54; p < 0.01) and asymmetric index (9.75 ± 6.63 to 7.01 ± 4.77; p < 0.01) also showed improvements.

Conclusions: The Nuss procedure may contribute positively to the physical development of patients with pectus excavatum.

Keywords: Nuss procedure, chest wall, pectus excavatum, physical development

Introduction

Pectus excavatum is a relatively common congenital chest wall deformity with posterior depression of the sternum that often presents with physiological as well as cosmetic issues. The most classical surgical technique for correction of pectus excavatum, as described by Ravitch, involves the removal of abnormal cartilage with preservation of the perichondrium, sternal elevation, and stabilization.1 In 1998, Nuss et al.2 published a report describing a minimally invasive technique that raises the sternum with a retrosternal metallic bar placed for remodeling the anterior chest wall. The Nuss procedure presents the advantages of actually correcting the anatomy of the thorax, with little scarring and obviating the need for cartilage resection. This new approach was designed to improve functional and cosmetic outcomes, and it has gained acceptance worldwide as the new standard of care procedure.3,4 The morphological results of pectus excavatum correction, in terms of improvement in depression or asymmetry, can be evaluated by the Haller computed tomographic index (CTI)5 or the asymmetric index (AI) and the angle of sternal rotation (ASR)6,7 as objective radiographic markers.

Previous studies have shown that the backward angulation of the breastbone might be related to geometric changes of the heart, which might influence myocardial...
Cardiopulmonary functions have also been found to improve following the Nuss procedure,\(^8\) with the creation of sufficient space between the sternum and the vertebral bodies that relieves cardiac or pulmonary compression.\(^12\) Park et al. described a phenomenon whereby younger patients with pectus excavatum experienced varying degrees of growth restriction that improved after the Nuss procedure\(^13\); they concluded that this phenomenon might be related to relief from cardiac compression.

This study aimed to determine the effect of pectus excavatum on physical development of patients and compared their development with that of the normal population as well as to assess how correction of pectus excavatum by using the Nuss procedure affects physical development.

**Materials and Methods**

**Patients**

A total of 146 patients consisting of 35 females and 111 males underwent the Nuss procedure at the Korea University Guro Hospital. Of these, 123 patients (84.9%) had the bar removed between December 2002 and January 2014. All patients opted for the Nuss procedure for cosmetic reasons, and all were counseled regarding the risks and potential complications. Patients with Marfan syndrome or other congenital disease were not included in this study. After approval by the institutional review board of Korea University Guro Hospital (KUGH11272), written informed consent was obtained from all patients in accordance with the Declaration of Helsinki.

**Surgery**

The techniques used in the Nuss procedure for the correction of pectus excavatum have been described previously.\(^4,14\) The procedure is based on the original technique described by Nuss et al.\(^2\) and includes the following steps:

1. 1-cm transverse incisions are made bilaterally at the midaxillary line; 2) the serratus anterior muscles are dissected away from the ribs by using electrocautery to construct sufficient submuscular pockets, and submuscular tunnels to the hinge points are then created; 3) the bar (MX-bar system; Medix Align Technology, Seoul, Korea) is passed across the mediastinum under the depressed sternum and rotated 180° to elevate the chest wall depression; 4) both ends of the bar are placed between the ribs and the serratus anterior muscles; 5) the right hinge point of the bar is firmly fixed with polydioxanone (PDS 1-0) sutures; and 6) both ends of the bar are firmly fixed in the submuscular pockets by suturing to the muscles with PDS 1-0. Postoperative patient care was according to the routine protocol of the hospital. Patients were transferred to the intensive care unit for 1 day; none of the patients required ventilator support. A patient-controlled anesthesia pump was used for management of postoperative pain. All patients were asked to maintain the supine position during the immediate postoperative period, a 45° semi-Fowler position at 3 days postoperatively, and a sitting position at 5 days postoperatively. Ambulation was started on the sixth postoperative day. The removal of the pectus bar was scheduled 2 to 3 years after the Nuss procedure, depending on the subjective postoperative condition of each patient.

**Height and weight**

Heights and body weights of the patients were measured prior to surgery and immediately before bar removal. To compare the developments of height and weight with those of the normal population, height and weight data were converted into age- and sex-adjusted standard deviation scores (SDS) using the standard growth chart for Korean children and adolescents published by the Korean Pediatric Society,\(^15\) which was compiled from multicenter surveys performed over a comparable time span throughout Korea. The height SDS and weight SDS, according to biological age and sex, were calculated as the difference between the measured height and weight. The average heights and weights, according to age and sex, were...
Indices measured using chest CT

Chest CT was performed preoperatively and immediately before bar removal to evaluate any problematic structures surrounding the pectus bar. CTI\(^5\) was computed using the CT slice that showed the deepest part of the sternum or xiphoid. ASR was measured using the chest CT image; a slice depicting the sharpest sternal twist was selected. The angle was defined as the sternal slope against the baseline, connecting the left and right dorsal ends of the thorax\(^6\) (Fig. 1). AI was measured using the chest CT slice showing the greatest difference between the right and left intrathoracic anteroposterior diameters, and it was defined as the ratio of the right and left intrathoracic anteroposterior diameters.\(^7\)

Statistical analyses

Linear regression and multivariate analyses were used to assess the association between physical development and chest CT indices according to the time interval. In addition, the Spearman rank correlation was used to evaluate the correlation between chest CT indices. Significance was set at a \(p < 0.05\). Statistical analyses were performed using statistical software (SPSS for Windows, release 19.0; SPSS Inc., Chicago, IL, USA; and SAS for Windows, release 9.3; SAS Institute Inc., Cary, NC, USA).

Results

Surgical data

The mean patient age was 8.7 ± 4.39 years at the time of the Nuss procedure and 10.6 ± 4.49 years at the time of bar removal. Patient distributions according to age and sex are...
shown in Fig. 2. The pectus bar size was 10.5 ± 1.80 inches. All Nuss procedures were completed successfully without any required conversion to the Ravitch procedure; bar removals were also completed successfully. During the Nuss procedure, one patient required the stabilizer to be fixed to the edge of the bar unilaterally and two patients required placement of a second bar. These problems occurred only in patients with asymmetric pectus excavatum. Major complications, such as injuries to intrathoracic organs, did not occur. One case of bar dislodgement (0.8%) occurred and was managed with surgical repositioning. Pneumothorax occurred in four patients (3.25%) and was successfully treated via catheter-guided aspiration. Hemothorax developed in one patient (0.8%) with asymmetric pectus excavatum, which was managed successfully with closed thoracostomy without surgical intervention. Surgical site infection occurred in one patient and was initially treated with antibiotics; however, because this failed to control the infection, the Nuss bar was removed 18 months sooner than was scheduled. One case of pericardial effusion (0.8%) was well controlled after pericardiostomy. A single case of pulmonary edema (0.8%) and a case of atelectasis (0.8%) was observed; both improved after conservative management.

**Height and weight**

Significant differences in the height SDS and weight SDS were apparent between the two time points. The height SDS was −0.66 ± 2.23 preoperatively and was 0.04 ± 1.34 immediately before bar removal (p < 0.01) (Fig. 3). The weight SDS was −0.02 ± 2.59 preoperatively; increased significantly to 0.56 ± 1.56 immediately before bar removal (p < 0.01).

**Radiologic indices**

Preoperative CTI was 3.85 ± 1.18; this significantly improved (2.99 ± 0.54) at the final follow-up (p < 0.01) (Fig. 4). Preoperative AI was 9.75 ± 6.63; this significantly decreased (7.01 ± 4.77) at the time of bar removal (p < 0.01). Preoperative ASR was 1.06 ± 0.09°; this had not changed significantly by the time of bar removal (1.06 ± 0.05°; p = 0.26).

**Correlation**

The difference between height SDS preoperatively and immediately before bar removal correlated with the corresponding difference in CTI, but not with AI or ASR (Table 1, Fig. 5). The difference between preoperative weight SDS and before bar removal strongly correlated with the corresponding difference in CTI, but not with AI or ASR.

**Discussion**

Our study showed that height and weight were lower in patients with pectus excavatum before surgery when compared with the normal population. However, these measures improved to values similar to those of the normal population by approximately 2 years postoperatively (immediately before bar removal). These findings suggest that the Nuss procedure had a positive normalizing effect on physical development. In other words, the results showed that patients with pectus excavatum had reduced physical development compared to the normal population and were good candidates for the Nuss procedure.

The Nuss procedure had a significant effect on the CTI and AI. However, the ASR was unchanged.

The differences in height and weight SDS over time strongly correlated with the differences in CTI. Since the patients could not be followed-up periodically, we considered age 13 as the peak height velocity of male patients and age 10 as the peak height velocity of female patients. In addition, we considered age 18 as end of the male growth spurt and age 15 as the end of the female growth
spurt. All patients experienced the growth period before undergoing the Nuss procedure. These results might suggest that sternal elevation is related to changes in the physical development prior to and after the Nuss procedure. One possible interpretation is that the functions of the heart and lungs are impaired preoperatively due to compression of these organs within the bony thorax. This would result in impaired circulatory function and, therefore, underdevelopment. The Nuss procedure results in elevation of the sternum, thus releasing the organs from compression. The resulting adequate circulation of blood throughout the body may restore the physical development of patients with pectus excavatum. Further studies are needed to determine the effects of the Nuss procedure on other factors such as cardiopulmonary function.

This study has several limitations, such as the lack of a comparative group of age-matched children with pectus excavatum who did not undergo the Nuss procedure, the use of the Korean growth chart (which limits the generalization of our results), the lack of cardiopulmonary preoperative and postoperative evaluations, and the lack of long-term follow-up. Moreover, nutritional status and exercise related to physical development were not evaluated in this study.

In conclusion, the results of this study suggest that the Nuss procedure may have a positive effect on the physical development of patients with pectus excavatum.

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Author Contributions

H.K.K. supervised and designed the overall study, collected and analyzed data, and co-wrote the paper. J.Y.Y. collected and analyzed data and co-wrote the paper. K.N.H. discussed and edited the paper. Y.H.C. discussed and edited the paper.

Disclosure Statement

The authors have no conflict of interest.

References


