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Article

Feasibility of the Nuss Procedure in Children with Pectus Excavatum following Congenital Heart Surgery: A Single-Center Retrospective Study

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Abstract

Background: The Nuss procedure is widely used for correcting pectus excavatum. However, the likelihood of dense substernal adhesion is high in patients with pectus excavatum after post-congenital heart disease surgery; thus, collaboration between a congenital cardiac surgeon and a thoracic surgeon is necessary for safe surgery. This study aimed to verify the feasibility of pectus surgery in children with pectus excavatum following cardiac surgery. **Methods**: In total, 18 patients who underwent pectus procedures for pectus excavatum from February 2011 to September 2023 and who developed after surgery for congenital heart disease were retrospectively analyzed based on their medical records. A thoracic surgeon and a congenital heart surgeon performed the surgeries. **Results**: The duration from cardiac surgery to Nuss surgery was 68.6 $\pm$ 38.44 months. The Nuss procedure was performed for cosmetic purposes: simultaneous Nuss surgery during conduit change, right ventricle decompression, airway decompression, and right pulmonary artery decompression in 10 (55.6%), three (16.7%), two (11.2%), two (11.2%), and one (5.6%) patient(s), respectively. The mean surgical time for Nuss bar insertion and hospitalization period was 148.6 $\pm$ 53.86 minutes and 8.4 $\pm$ 3.19 days, respectively. Twelve patients underwent Nuss bar insertion under partial sternotomy, and five patients underwent surgery using sternotomy. In one case, cardiac perforation occurred during partial sternotomy. Therefore, cardiac repair was performed using cardiopulmonary bypass after sternotomy. **Conclusions**: Severe adhesions between the heart and substernum from previous surgeries increase the risk of cardiac rupture during surgery; thus, collaboration with experienced congenital cardiac surgeons is essential. Careful planning and teamwork are fundamental to achieving good surgical outcomes.

Keywords

pectus excavatum; Nuss procedure; congenital heart surgery

Introduction

The Nuss procedure was introduced in 1998 and enables correction of pectus excavatum without cartilage resection or sternal osteotomy, making it the most commonly used method today [1]. This approach, which does not involve cartilage resection, offers many advantages over the traditional Ravitch technique. However, the pectus procedure inherently carries the risk of cardiac rupture due to the substernal blunt dissection required for bar insertion [2,3]. Many institutions have used thoracoscopes for substernal dissection to reduce this risk [4,5].

Efforts to decrease the incidence of cardiac rupture through surgeries guided by a videoscope have been reported recently, with virtually no occurrences of cardiac rupture. However, the likelihood of dense substernal adhesion is high in patients with pectus excavatum after surgery for congenital cardiac disease. Therefore, even with videoscope-guided substernal dissection, the risk of cardiac rupture always exists. For safe surgery, meticulous dissection by an expert cardiac surgeon is essential for bar insertion and securing rotation space, necessitating collaboration between a congenital cardiac surgeon and a thoracic surgeon [6–8]. This study aimed to verify the feasibility of pectus surgery in children with pectus excavatum following cardiac surgery through an analysis of clinical results over several years.

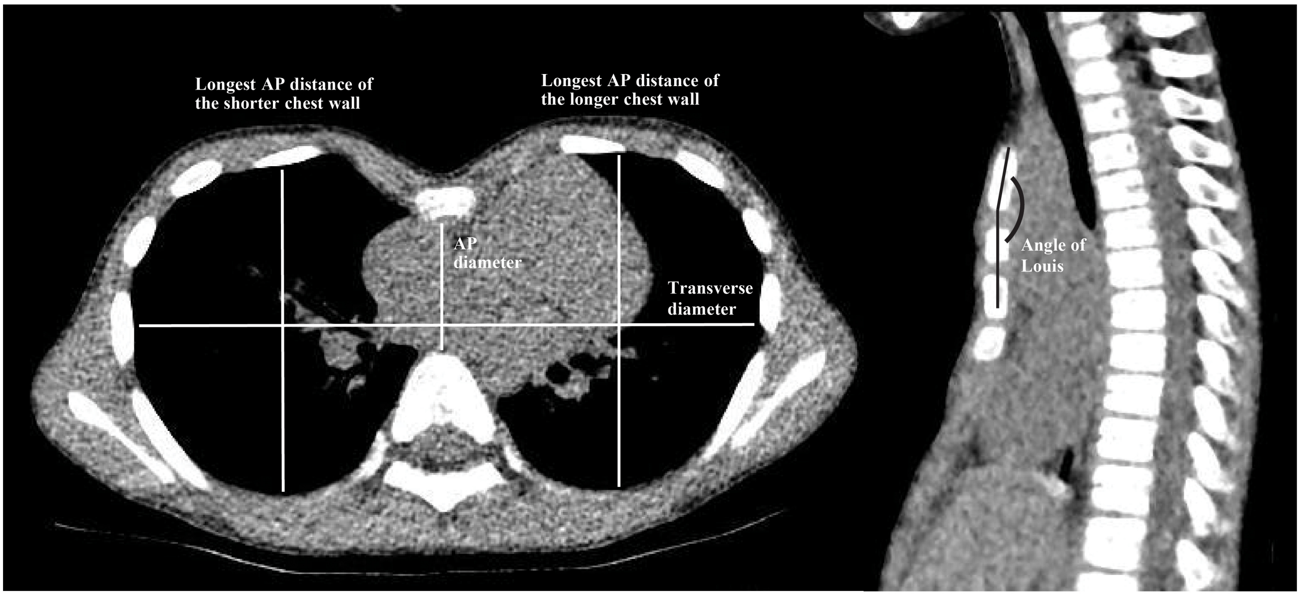


Fig. 1. Definition of variables representing pectus index. The transverse and antero-posterior (AP) diameters are used to calculate the Haller index. The longest antero-posterior distances of both chest walls determine the Asymmetry index. The Angle of Louis is measured in the sagittal plane.

Materials ad Methods

Evaluation of the Severity and Type of Pectus Excavatum

Haller index (HI), Asymmetry index (AI), and Angle of Louis (AoL) were measured to evaluate the severity of pectus excavatum [9]. (Fig. 1).

- HI = (Transverse diameter of the chest wall) / (Antero-posterior diameter of the chest wall and vertebra)
- AI = (longest anteroposterior distance of the longer chest wall) / (longest anteroposterior distance of the shorter chest wall)
- AoL = angle between the manubrium and body of the sternum in the sagittal plane.

Operation Procedure

Nuss Bar Insertion Technique

To determine the extent of incision in patients for whom surgery was decided, a multidisciplinary approach was taken through collaboration between the general thoracic department and pediatric cardiac surgery department. Based on previous surgical methods, records, and imaging tests, the degree of adhesion was determined, and the bar insertion site and surgical method were considered. In the Nuss procedure and sternotomy, patients were placed in a supine position with both arms spread. Because of the risk of cardiac rupture during surgery, preparation was performed, including the femoral area. For the same reason, we prepared to immediately start extracorporeal membrane oxygenation (ECMO) or cardiopulmonary bypass (CPB) in an emergency situation.

An expert cardiac surgeon performed partial sternotomy. Full sternotomy was performed if cardiac surgery or replacement of a new vascular conduit was required. Initially, we performed a full sternotomy in all cases, completely dissecting the anterior portions of the heart and major vessels. However, currently, we perform osteotomy on the lower two-thirds of the sternum and perform sufficient substernal dissection for bar insertion and rotation (Fig. 2A). Dissection was performed carefully to prevent cardiac injury, and if perforation occurred, repair of the bleeding site was performed by applying ECMO or CPB, as necessary. If cardiac or vascular surgery using a heart-lung machine was necessary, cardiovascular surgery was performed first, followed by pectus surgery. Once dissection was complete, the bar insertion site was set one level above the most depressed area rather than lifting the most depressed area using the conventional technique. After the incision site and hinge point on both sides of the chest were determined, pectus bar molding was performed. A 2-cm skin incision was made laterally in the thoracic cavity, and extrathoracic dissection was conducted for bar insertion (Fig. 2B). After submuscular area dissection, the intercostal space at the hinge point was punctured at a right angle. During this process, a thoracoscope was inserted into the partial sternotomy site to prevent damage to the lungs and heart, and a long Kelly was used to insert a nylon tape guide for the bar. The right side of the nylon tape was attached to the pectus bar, and the already molded pectus bar was inserted into the chest under nylon tape guidance. The shaped bar was pushed with the guide and positioned under

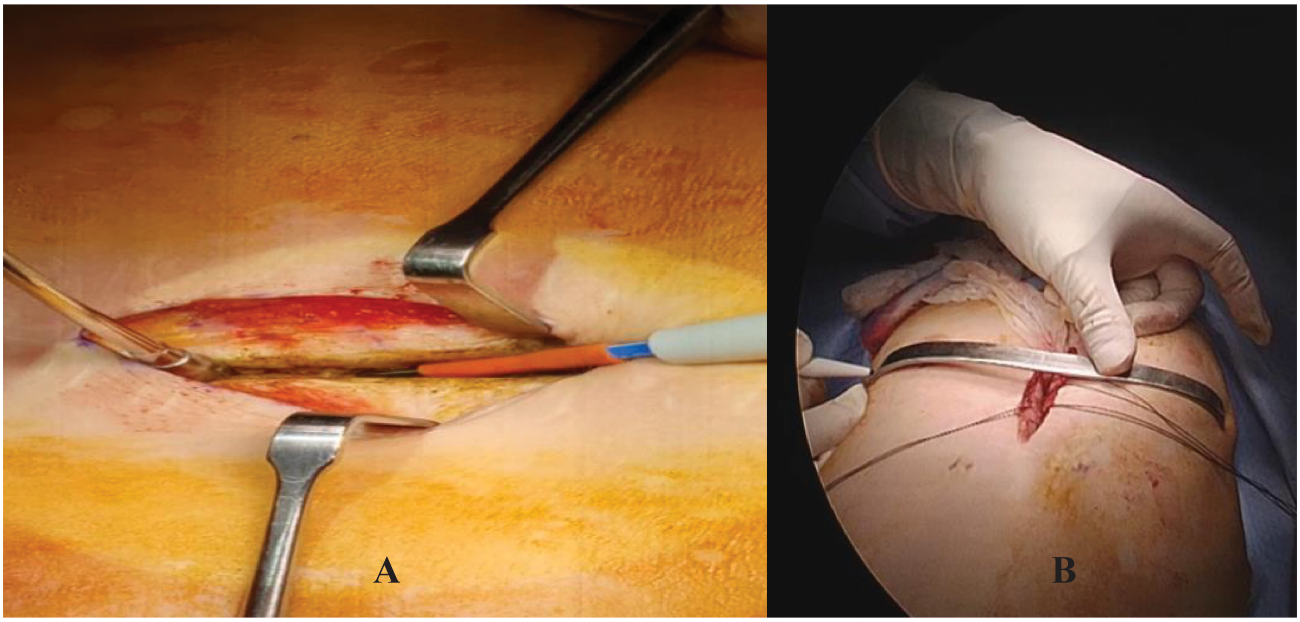
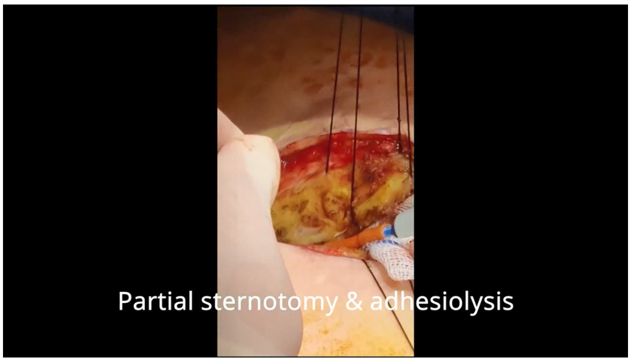


Fig. 2. Partial sternotomy and bar insertion technique. (A) Partial sternotomy was performed by incision of the lower 2/3 of the sternum, and sufficient substernal dissection was performed to allow for bar insertion and rotation. (B) After the incision site and hinge point on both sides of the chest were determined, pectus bar molding was performed.

the depressed sternum, with the convex side facing downward. Using the pectus bar flipper, the bar was turned over so that the convex side of the bar pushed up the depressed chest wall. Once the chest wall depression was elevated to the target level, the bar was secured on both sides. A crow fixator was used for stabilization when chest wall rigidity was required to allow bar rotation. The sternum was not additionally secured, and after chest tube insertion, wound closure was performed to conclude the surgery (Video 1).



Video 1. This video demonstrates partial sternotomy and insertion of a Nuss bar, with removal of substernal adhesion. After determining the incision site and hinge points on both sides of the chest, the pectus bar is molded. After creating a submuscular area, a thoracoscope is inserted through the partial sternotomy site to avoid damaging the lungs and heart. The molded pectus bar is guided into the chest under nylon tape, and a crow fixator is used for stabilization once the chest wall rigidity allows for bar rotation. The embedded movie may also be viewed at https://doi.org/10.59958/hsf.8305.

Nuss Bar Removal Technique

First, chest computed tomography (CT) was performed before bar removal to check for adhesions in the substernal area. If it was determined that there was sufficient space between the heart and sternum due to the correction, bar removal was performed under thoracoscopic guidance without partial sternotomy. The area around the bar was dissected, starting from the incision site used for insertion on the right side, and any stitches, wires, or fixators used to secure it were removed. A thoracoscope was then inserted into the intercostal space one level above the incision site to dissect around the heart and bar. The same process was repeated on the left side. If it was deemed that enough dissection had been performed to allow bar rotation, the pectus bar flipper was used to flip the bar so that its convex side faced downwards. After rotation was performed on both sides to separate any surrounding adhesions, the bar was slowly removed under thoracoscopic guidance. It is advisable to perform the removal from the right side. After the bar was removed, bleeding was checked, chest tubes were inserted on both sides, and the surgery was completed. If there was cardiomegaly due to congenital heart disease and the heart was close to the sternum, the same method as insertion was used for extrinsic decompression: partial sternotomy and adhesiolysis followed by bar removal.

Statistical Analysis

Categorical data are presented as the number of patients with percentages in parentheses, median, minimum, and maximum, depending on its distribution. Quantitative variables are reported as mean ± standard deviation (SD). Data analysis was performed using IBM SPSS Statistics (ver. 22.0; IBM Corp., Armonk, NY, USA).

Results

General Patient Information

From February 2011 to September 2023, a total of 18 patients who underwent pectus procedures for pectus excavatum developed after surgery for congenital heart disease were retrospectively analyzed based on medical records. The surgeries were performed by a thoracic surgeon and a congenital heart surgeon. Among the 18 patients, 11 were male and 7 were female, with a median age of 5 years (3–17). Ten patients had no other diseases except for a history of heart surgery, and five patients had genetic diseases. CT was performed in all patients to evaluate chest wall deformity before surgery, showing median Haller index (HI) and AI of 4.29 (2.99–7.47) and 1.043 (1.004–1.090), respectively. To determine the characteristics of pectus excavatum after congenital surgery, the angle between the manubrium and body of the sternum [AoL] was analyzed, and the median value was measured at 163.8 (122.9–176.4). The most common cause of previous heart surgery was ventricular septal defect in nine patients, followed by atrial septal defect in five patients (Table 1). In this study, the basic characteristics of patients, purpose of surgery, postoperative results, and complications were analyzed, and the degree of chest wall deformity was evaluated in patients who underwent postoperative CT.

Table 1. General patient information.

Variable (n = 18)	Number of patients (%) Median (range)
Gender (Male:Female)	11:7
Age	5 (3–17)
HI	4.29 (2.99–7.74)
AI	1.043 (1.004–1.090)
AoL	163.8 (122.9–176.4)
Associated disease	
Down syndrome	2 (11.1%)
Catch 22 syndrome	1 (5.6%)
Chromosomal abnormality 46,XY	1 (5.6%)
Chromosomal abnormality 46,XX	1 (5.6%)
Neurofibromatosis	2 (11.1%)
Scoliosis	2 (11.1%)
Not reported	10 (55.6%)
Primary cardiac diagnosis	
Ventricular septal defect	9 (50.0%)
Atrial septal defect	5 (27.8%)
Atrioventricular septal defect	1 (5.6%)
Tetralogy of Fallot	3 (16.7%)
Coarctation of the aorta	1 (5.6%)
Double outlet right ventricle	2 (11.1%)
Pulmonary artery sling	1 (5.6%)
Dilated cardiomyopathy	1 (5.6%)
Pulmonary atresia	1 (5.6%)
Surgical procedures for congenital heart disease	
Total correction of Tetralogy of Fallot	3 (16.7%)
Closure of ventricular septal defect	9 (50.0%)
Closure of atrial septal defect	5 (27.8%)
Rastelli's procedure	2 (11.1%)
Glenn's procedure	1 (5.6%)
Repair of coarctation of the aorta	1 (5.6%)
Repair of atrioventricular septal defect	1 (5.6%)
Right pulmonary artery anterior translocation	1 (5.6%)
Left pulmonary artery angioplasty	1 (5.6%)
Heart transplantation	1 (5.6%)

Some patients had multiple defects.

AI, Asymmetry index; AoL, Angle of Louis; HI, Haller index.

Perioperative Information

Nuss insertion was successfully performed in all 18 patients who underwent surgery. The duration from cardiac surgery to Nuss surgery was 68.6 ± 38.44 months. Thirteen (72.2%), four (22.2%), and one (5.6%) patient had previously undergone sternotomy once, twice, and more than three times, respectively. Ten patients (55.6%) underwent surgery for cosmetic purposes rather than for functional problems, and three patients (16.7%) underwent simultaneous Nuss surgery during conduit change. Among patients who underwent Nuss surgery for functional problems, two (11.2%), two (11.2%), and one (5.6%) patient underwent right ventricle decompression, airway decompression, and right pulmonary artery decompression, respectively (Table 2, Fig. 3).

Operative Result of Pectus Bar Insertion

The mean surgical time for Nuss bar insertion was 148.6 ± 53.86 minutes, and the mean amount of intraoperative bleeding was 54.4 ± 29.75 mL. The mean chest tube duration was 3.8 ± 1.83 days, and the mean hospitalization period was 8.4 ± 3.19 days. Twelve patients underwent Nuss bar insertion under partial sternotomy, five patients underwent surgery using sternotomy, and one patient underwent surgery using subxiphoid blunt dissection under video assistance. Complications related to surgery included one case of pneumothorax, one case of hemothorax, and two cases of wound infection. In one case of wound infec-

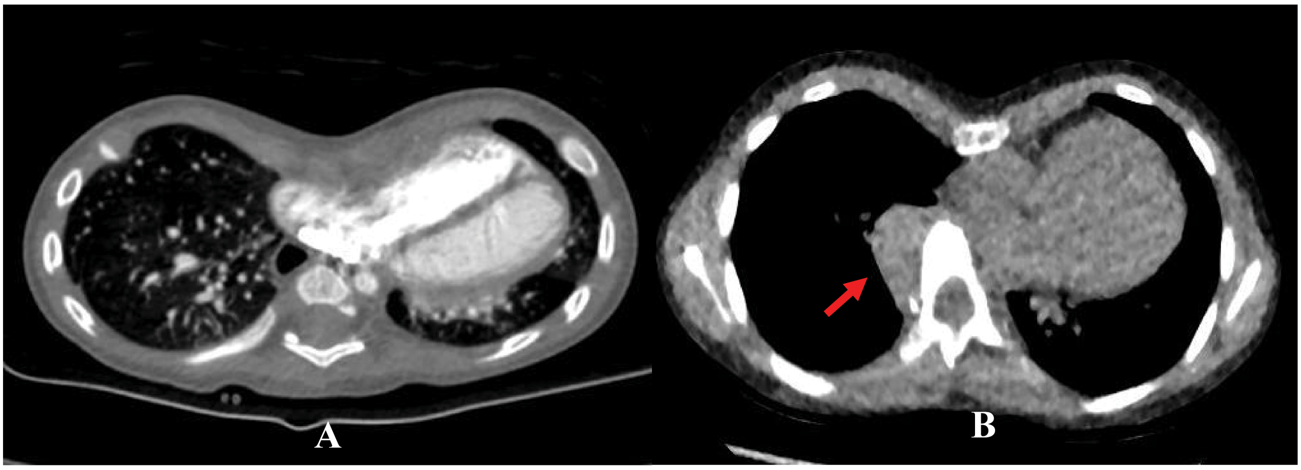


Fig 3. Right ventricle and airway compression in pectus excavatum. (A,B) Computed tomography image showing right ventricle compression caused by pectus excavatum and atelectasis caused by airway compression. The red arrow indicates atelectasis caused by airway compression.

Table 2. Perioperative information.

	Number of patients (%)/ mean ± SD
Purpose of the Nuss procedure	
Cosmetic	10 (55.6%)
Right ventricle decompression	2 (11.1%)
Simultaneous surgery during conduit change	3 (16.7%)
Airway decompression	2 (11.1%)
Pulmonary artery decompression	1 (5.6%)
Previous sternotomy	
1	13 (72.2%)
2	4 (22.2%)
More than 3	1 (5.6%)
Duration from cardiac surgery (months)	68.6 ± 38.44

SD, standard deviation.

Table 3. Results of Nuss bar insertion.

Variable	Value
Mean blood loss (mL)	54.4 ± 29.75
Operative time (min)	148.6 ± 53.86
Chest tube duration (days)	3.8 ± 1.83
Hospital stay (days)	8.4 ± 3.19
Procedure techniques	
Sternotomy	5 (27.8%)
Partial sternotomy	12 (66.7%)
Subxiphoid blunt dissection, video-assisted	1 (5.6%)
Complication	
Pneumothorax	1 (5.6%)
Hemothorax	1 (5.6%)
Wound infection	2 (11.1%)
CPB due to cardiac perforation	1 (5.6%)
Failure of correction	1 (5.6%)
Postoperative results	
Postoperative HI (n = 13)	2.95 (2.2–7.2)
Postoperative AI (n = 13)	1.024 (1.01–1.063)

CPB, cardiopulmonary bypass.

tion, bar removal was performed one-year post-op due to delayed infection at the bar insertion site. Additionally, in one case, cardiac perforation occurred during partial sternotomy. Thus, cardiac repair was performed by applying CBP after sternotomy, and subsequent Nuss surgery was completed. In one patient, chest wall depression progressed again during follow-up, in which Nuss removal and reinsertion were performed two years after surgery.

In 13 patients who underwent computed tomography after Nuss insertion, the HI was 2.95 (2.21–7.27), and the AI was 1.024 (1.01–1.063), showing improvement in chest wall deformity. Furthermore, in patients who underwent surgery to solve extrinsic compression, the problem was confirmed to be resolved (Table 3, Fig. 4).

Operative Result of Pectus Bar Removal

Bar removal was performed in 8 of 18 patients, and the median period from insertion to removal was 25 months (10–36). The median operation time was 50 minutes (30–130), and the median blood loss was 30 mL (20–60). The median hospitalization period was 5 (2–14) days, and there were no special complications in all patients.

The incision for Nuss bar removal was determined by judging the degree of adhesion using information from previous surgery and CT.

Partial sternotomy was performed in five patients, among which it was performed through the bilateral Nuss insertion site without sternotomy in two patients, while in one case, removal was performed under thoracoscopy, and full sternotomy was not performed (Table 4).

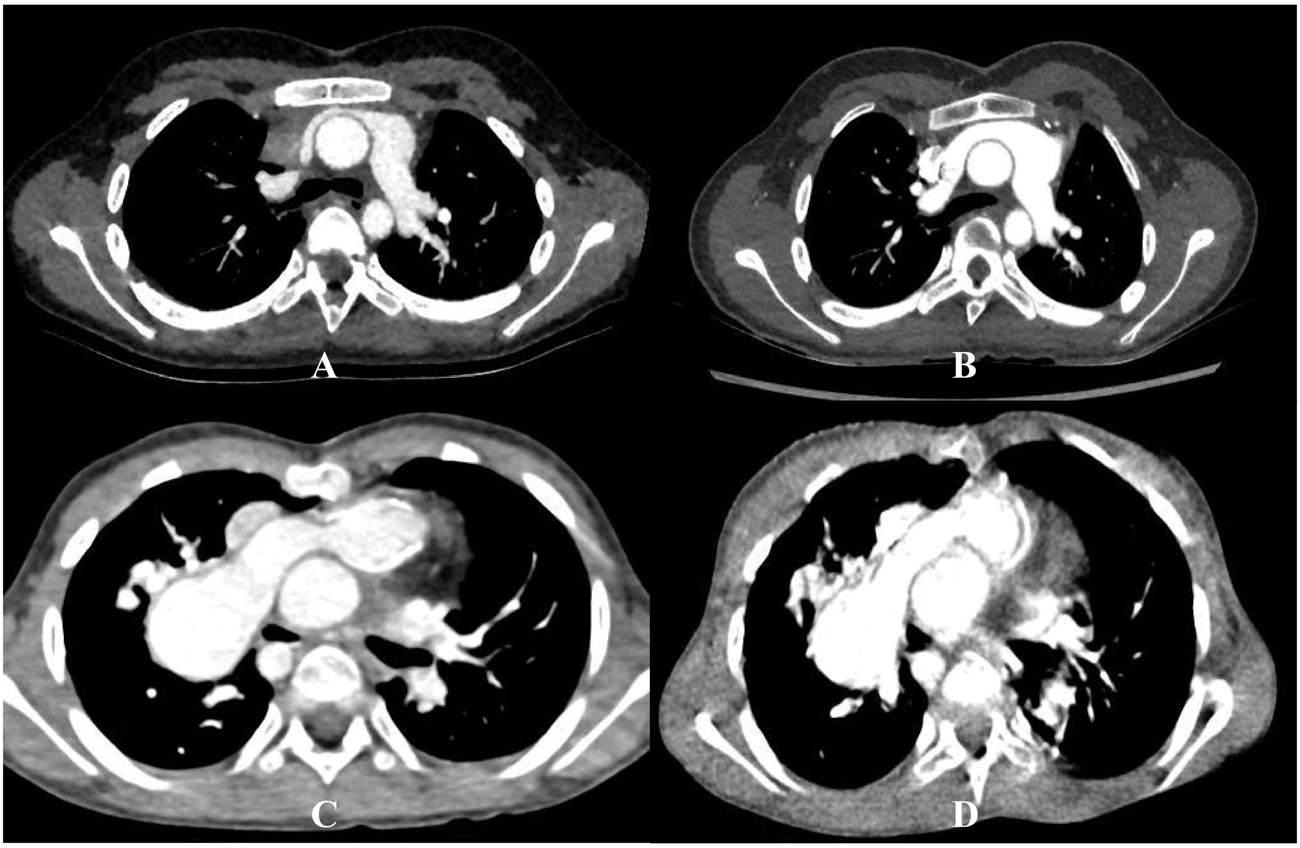


Fig 4. Resolution of right pulmonary artery and right ventricular outflow tract compression after nuss procedure. (A) Computed tomography image showing compression of the translocated right pulmonary artery (RPA). (B) The compression was resolved after the Nuss procedure, and the RPA became patent. (C,D) The compression of the right ventricular outflow tract was resolved after the Nuss surgery.

Table 4. Results of Nuss bar removal.

Variable (n = 8)	Value
Duration from Nuss insertion (months)	25 (10–36)
Operative time (min)	50 (30–130)
Blood loss (mL)	30 (20–60)
Hospital stay (days)	5 (2–14)
Chest tube duration (days)	3 (0–10)
Incision of bar removal	
Conventional	2 (25.0%)
Video-assisted	1 (12.5%)
Partial sternotomy	5 (62.5%)
Sternotomy	0

Discussion

Children with pectus excavatum that develops after a cardiac operation generally have a wider range of sternal depression than typical pectus excavatum cases. Owing to the impact of mid-sternotomy, the development of the sternum is often impaired, resulting in a smaller sternum size and a depression that extends from above the manubrium with a greater-than-average AoL. In many cases of pectus excavatum, the sternum shows no depression, while only the costal cartilage portion is depressed; however, in children who have undergone cardiac operations, both the sternum and costal cartilage tend to be generally depressed together. In infants, where sternal growth has not occurred, the sternal cartilage portion remains apart before fusion but naturally fuses as it grows [10,11]. In children who have undergone cardiac surgery in infancy, the bilateral costal cartilages, which are drawn centrally through direct wiring or suturing to the sternum, are thought to cause excessive approximation, inducing downward growth of the entire anterior chest wall, including the costal cartilage. As pectus excavatum progresses, cardiac morphology also changes, and depending on the location of the depression, extrinsic compression of major cardiac and vascular structures occurs [12]. Due to the wider range of depression compared to typical pectus excavatum, this can excessively compress important structures above the heart, such as the head vessels and pulmonary artery, potentially causing functional defects. Surgery to resolve extrinsic compression caused by pectus excavatum following congenital heart surgery represents a new indication for pectus surgery [6,13].

In addition, recent research indicating that myocardial strain parameters can be impaired in cases of chest wall deformity with a narrowed anteroposterior thoracic diameter highlight the advantages of surgical treatment [14,15]. However, in patients who have previously undergone congenital heart surgery, this treatment must be decided with caution because it can cause dangerous complications, such as cardiac perforation. According to another report, the probability of cardiac perforation occurring during Nuss surgery in patients undergoing surgery for congenital heart disease was approximately 7%. Although this is not highly probable, it can be fatal. Thus, surgery should be performed in a way that ensures safety, and easy and hasty indications should be avoided considering the patient's condition and history [16].

Determining the extent of substernal dissection is crucial. It must be determined whether complete separation of the heart and sternum or sufficient dissection for bar insertion and rotation is required. Initially, we chose to perform a full sternotomy and completely separate the heart and sternum before inserting the bar. However, this method posed problems during the process of sternum closure. The sternum of many patients was not flat but concave inward, making sternal approximation difficult after inserting the rounded bar. The lower cortical bone could be approximated during approximation, but the lower part often could not. For these reasons, we changed our surgical approach to performing osteotomy on the lower two-thirds of the sternum and performing only enough substernal dissection to allow bar insertion and rotation. After inserting the bar, we did not close the sternotomy site. The upper part of the sternum, where sternotomy was not performed, was supported by the inserted bar to prevent sternal instability, which showed better clinical outcomes than a forceful sternal approximation.

Additionally, we placed the bar insertion site one level above the most depressed area instead of using the conventional technique. Initially, we chose the bar insertion site using the same criteria as in the conventional technique. However, the correction was not always effective, and in some cases, depression recurred above the inserted bar. As mentioned earlier, our current practice is to insert the bar one level higher.

When performing bar removal, we do not perform substernal dissection after partial sternotomy. In most cases, sufficient dissection and sternal elevation during bar insertion maintain a distance between the heart structure and sternum, with the lungs mostly occupying the created space. Cases in which the heart and sternum are close, except in those with cardiomegaly due to congenital heart disease, are rare. Dense adhesions are suspected infrequently at removal, and cases with extensive adhesions between the heart and sternum are uncommon. In particular, since artificial pericardium or adhesion inhibitors are used for repair after bar insertion in most cases, substernal dissection under thoracoscopic guidance without re-sternotomy is feasible. For these reasons, in cases where bar removal was necessary, we were able to perform thoracoscope-assisted pectus bar removal without partial sternotomy [17,18]. Adequate space was secured in all cases, and it was judged safe to perform bar removal without re-sternotomy under thoracoscopic view.

Conclusions

This study demonstrated that pectus excavatum that develops after congenital heart surgery is influenced by the sternal development of infants, causing extensive and complex deformities. Therefore, a surgical plan that considers previous heart surgeries is necessary. Additionally, severe adhesions between the heart and substernum due to previous surgeries increase the risk of cardiac rupture during surgery. Thus, collaboration with experienced congenital cardiac surgeons is essential. Careful planning and teamwork are fundamental to achieving good surgical outcomes.

Availability of Data and Materials

The data are available from the corresponding author upon request.

Author Contributions

Conceptualization: DHK. Data curation: JS, BSS and JMP. Formal analysis: JMP. Funding acquisition: JS. Investigation: All authors. Methodology: JS and BSS. Project administration: BSS and DHK. Resources: JMP. Software: JMP. Supervision: DHK. Validation: JS and BSS. Visualization: JMP. Writing—original draft: JS and BSS. Writing—review & editing: DHK. Read and approval of final manuscript: All authors. All authors contributed to editorial changes in the manuscript. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics Approval and Consent to Participate

The study was carried out in accordance with the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of Pusan National University Yangsan Hospital (Protocol No. 55-2024-074). This study was exempted from informed consent by the Ethics Committee of the Pusan National University Yangsan Hospital Review Board because it was a retrospective study.

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Conflict of Interest

The authors declare no conflict of interest.

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