A Retrospective Study on the Impact of Bar Flipping on the Recurrence of Pectus Excavatum after the Nuss Procedure

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Abstract

Background

The Nuss procedure is widely used to correct pectus excavatum. Bar displacement is a common complication associated with this procedure. How the flipping of the bar affects pectus excavatum recurrence has not been reported. In our study, we discuss this and also offer an easier method to determine bar flipping.

Methods

This retrospective study analyzed pectus excavatum patients who underwent primary Nuss repair from August 2014 to December 2018. The preoperative and postoperative Haller indices were measured on chest radiographs (cXRHI). The slope angle of bar flipping (α) was measured on lateral chest radiographs. The improvement index after surgical repair was calculated by: ([preoperative cXRHI-postoperative cXRHI]/preoperative cXRHI×100). The impact of α on the improvement index was analyzed using one-way analysis of variance and receiver operating characteristic tests.

Results

In this study, 359 adult and adolescent patients with an average age of 23.9±7.7 years were included. We formed four subgroups based on the α value: α ≤ 10° (n=131), α = 11-20° (n=154), α = 21-30° (n=51), and α > 30° (n=23). The mean improvement indices in these groups were 27%, 28%, 26%, and 13%, respectively. Patients with α > 30° were associated with a significantly poorer improvement index than those from the other subgroups (p<0.001).

Conclusions

The α value is an alternative measurement method for presenting the radiological outcomes after the Nuss procedure. An α > 30° indicates a possible recurrence of pectus excavatum after the Nuss repair. Surgical revision may be considered in patients with an α > 30°, while monitoring should be considered in the other patient groups.

Introduction

Pectus excavatum (PE), also known as funnel chest, is a structural deformity in which the sternum sinks in the center of the anterior chest wall. The exact cause of PE remains unknown. This congenital problem may become more severe in adolescence, as the chest wall deformation may be aggravated by an overgrowth of the costal cartilage. The estimated prevalence of PE in the adult population is 1 in 250 individuals. (1) Patients with PE do not only have a negative body image but also experience physical problems such as chest pain, exercise intolerance, dyspnea, sleep apnea, and rapid heart rate due to the compressive effects on the heart and lungs. (2) The Nuss procedure, first reported in 1988 by Nuss et al.,
is a minimally invasive method widely used to correct PE. In this method, metal bars are placed retrosternally, with the lateral ribs acting as hinge points, to lift the depressed chest wall.

Despite the excellent outcomes, a series of outcome studies have revealed that bar migration and PE recurrence are the major problems associated with the Nuss procedure.(3–6) The reported bar migration rates vary.(5–7) Previous investigators have classified the mechanisms of bar migration into bar flipping (bar rotates), lateral sliding (bar slides horizontally to one side), and hinge-point disruption (bar shifts dorsally).(7) According to our clinical observation, PE recurrence is most likely associated with bar flipping (to some degree) rather than lateral sliding. However, no study has investigated the association between bar flipping and outcomes of the Nuss procedure. Therefore, this study aimed to identify the association between the degree of bar flipping and PE recurrence. There is still no standard consensus on the measurement of the bar flipping degree. Hence, we designed a method to measure the slope of the bar and to estimate PE recurrence. Our study provides a guideline to survey and follow patients who may warrant revision surgery after the Nuss procedure.

**Methods**

Between August 2014 and December 2018, 374 patients underwent a primary repair for PE at the Taipei Chi-Tzu Hospital in New Taipei City, Taiwan. Of these, 367 patients received the Nuss repair, while seven received the Ravitch repair. Of the 367 patients who underwent the Nuss procedure, 359 were adolescents and adults above 12 years of age; these were included in this retrospective analysis (Fig. 1). This retrospective study was approved by the Ethics Committee and the Institutional Review Board of the Taipei Tzu Chi Hospital, Taipei, Taiwan, ROC (IRB No: 08-X-101). Patient consent requirement was waived by the institutional review board due to the study’s retrospective nature.

All surgeries were performed by a single surgeon (Dr. Cheng); the surgical technique followed has been described previously.(8) The indications for surgery were based on the criteria established by Nuss and Kelly.(9) Patients’ baseline characteristics, including sex, age, body weight, height, preoperative Haller index, and/or the presence of scoliosis, were recorded as preoperative assessments. Further preoperative examinations included chest radiography, electrocardiography, pulmonary function test, echocardiography, and chest computed tomography (CT). The Haller index (HI), which is the ratio of the maximum transverse thoracic diameter to the minimum sternal-to-anterior vertebral body distance,(10) was calculated on anteroposterior and lateral views of chest radiographs (cxrHI; Fig. 1) preoperatively (preop cxrHI) and postoperatively (postop cxrHI) to estimate the preoperative severity of PE and postoperative outcomes.(11) Because poor improvement in PE after surgery can indicate PE recurrence, we used the change of cxrHI (ΔcxrHI) (i.e., the improvement index) to estimate the degree of PE recurrence in an objective way using the following formula: [(preoperative cxrHI-postoperative cxrHI)/preoperative cxrHI]×100.

We also designed an easier method for measuring the degree of bar flipping by using the slope angle (α). On lateral chest radiography, α was measured as the angle between the two lines connecting the midpoint...
of the two end holes of the bar to 1) the uppermost part of the arch of the bended bar and 2) the expected point of the dorm’s optimal position (Fig. 2). The HI and the α on the chest radiograph were measured by an experienced surgeon and a radiologist, who were both blinded to the clinical data.

**Statistical Analyses**

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 24 (IBM Corp., Armonk, NY, USA). The Kolmogorov–Smirnov test revealed that all investigated parameters in our study were distributed normally. Continuous data were expressed as means ± standard deviations, while categorical data were expressed as counts (%). The optimal cuff-off value for the angle of bar flipping was determined by receiver operating characteristic (ROC) curve analysis. Based on the α of the most severe bar flipping, the patients were categorized into four groups, namely, α < 10°, α = 11–20°, α = 21–30°, and α > 30°. The improvement indices were compared between these groups using one-way analysis of variance (ANOVA), and the Scheffe test was used as a post hoc test. Using the cutoff value at α = 30°, the differences between the groups were analyzed using a two-sample t-test for continuous data and the chi-square test for categorical data. ROC curves were created using varying values for α as the categorization criteria and the I index to compare the best area under the curve (AUC) value. The DeLong test was further used to compare the C-statistic between different α values (12) (Fig. 3). ROC curve comparisons were conducted using R version 4.0.0 (pROC package). A p-value of < 0.05 was considered statistically significant.

**Results**

The study group comprised 304 men and 55 women with an average age of 23.9 ± 7.7 years. The mean postoperative follow-up period was 2.2 ± 1.3 years, while no individual follow-up was of < 6 months. The α = < 10°, α = 10–19°, α = 20–29°, and α > 30° groups comprised 131, 154, 51, and 23 patients, respectively (Table 1). The improvement indices in the α < 10°, α = 10–19°, α = 20–29°, and α > 30° groups were 27% (95% confidence interval [CI]: 17–37%), 28% (95% CI: 16–40%), 26% (95% CI: 14–38%), and 13% (95% CI: 4–22%), respectively (Table 1). The higher the improvement index, the more modest was the postoperative PE improvement. One-way ANOVA and post hoc analysis of the improvement indices within the groups revealed that an α > 30° was associated with a decreased improvement index, indicating a low clinical improvement (p < 0.001). There were no significant intergroup differences in the improvement indices when α < 30° (Table 2). ROC curve analysis, based on a grouping by an α of 10°, 20°, and 30°, revealed that grouping by 30° achieved the best AUC (0.828). Hence, grouping by α = 30° achieved excellent discrimination, while grouping by α = 10° (AUC = 0.532) or α = 20° (AUC = 0.621) achieved poor discrimination. The DeLong test for the three ROC curves also revealed that the AUC, when grouped by α = 30°, was significantly different from the AUCs when grouped by α = 10° or α = 20°; however, there were no significant differences in the AUCs when grouped by α = 10° and α = 20° (Fig. 3). Univariate analysis revealed that α > 30° was associated with significantly higher body weight and higher HI values. However, there were no significant differences in age at repair, the number of bars, follow-up period, sex, scoliosis,
or asymmetric body features between patients with $\alpha > 30^\circ$ and with $\alpha < 30^\circ$ (Table 3). Furthermore, 7 of 23 patients in the $\alpha > 30^\circ$ group voluntarily underwent a revision Nuss procedure after the comprehensive evaluation of significant recurrence and symptoms. These seven patients comprised five men and two women, and the mean age was $25 \pm 8.2$ years. The median (interquartile range [IQR]) period between the revision surgery and the first operation was 49 days (IQR: 27–71 days). Patients who underwent the revision Nuss procedure experienced a significantly greater improvement in the $\alpha$ and cxrHI values than after the first surgery ($p < 0.05$) (Table 4).

**Conclusions**

PE recurrence is the biggest concern in patients undergoing the Nuss procedure. In this study, the patients comprised adults who underwent an initial surgical PE repair. We introduced a simple and effective method for determining bar flipping. Our findings indicate that a bar flipping angle slope of $> 30^\circ$ is a predictor of PE recurrence and may require revision surgery. Our study’s limitations include its single-center, retrospective nature, and the fact that only one thoracic surgeon performed all surgeries. More cases are still required to support our findings. The Nuss procedure is an adequate follow-up intervention in patients with PE recurrence who underwent the Nuss procedure as the primary repair; however, a long-term follow-up is still required for such patients.

**Discussion**

The reported bar migration rate has decreased due to improvements in the fixation technique, surgical experience, bar sizing, and bending configuration.(6) However, bar displacement remains the most common complication.(13) In our study, we used the lateral fixation method bilaterally with wire or stabilizers. The majority of the bar displacements in our cases were due to bar flipping, although we did encounter a few inconspicuous lateral migration and undetectable dorsal shift migration cases that could be disregarded. We believe that bar flipping can affect surgical outcomes. To date, no studies have examined whether bar flipping affects PE recurrence. Furthermore, the measurement of bar flipping is currently inconsistent.

Thus, we would like to offer a simple and effective way to measure bar flipping by calculating the angle between the two lines connecting the midpoint of the two end holes to the dorm of the bar and to the midpoint where the dorm is optimally positioned (as visualized in the lateral view of chest radiography). PE recurrence remains the most important unsatisfactory outcome of the Nuss repair. Previous studies have reported that the risk factors for PE recurrence after the Nuss procedure include surgical complications, younger age, earlier bar removal, higher HI, and higher body weight.(3–6)

In this study, we have focused on PE recurrence before bar removal. We believe that bar flipping may affect PE recurrence to some degree; however, in some cases, there is no obvious chest wall recession despite signs of bar flipping during postoperative follow-up chest radiography. Upon reviewing articles, we found no studies that discussed the impact of bar flipping on PE recurrence. Kelly et al. reported that a
bar movement of $\alpha > 15^\circ$ is indicative for operative repositioning.(6) Cho et al. defined bar displacement $\alpha > 20^\circ$ as severe bar migration.(14) In our study, no statistical differences in PE improvement were observed between the following groups: $\alpha < 10^\circ$, $\alpha = 10–19^\circ$, and $\alpha = 20–29^\circ$. Because poor improvement in PE after surgery can indicate PE recurrence, we used ($\Delta cxr$HI) and the change of pre- and postoperative $cxr$HI (i.e., the improvement index) to estimate the degree of PE recurrence objectively (which was previously described subjectively and based on the patient’s clinical findings).(3–6, 14)

We found that an $\alpha$ of $> 30^\circ$ was significantly correlated with PE recurrence. ROC analysis confirmed that an $\alpha$ of 30° offers excellent discrimination and is the best criterion for identifying PE recurrence. In our previous study, postoperative changes in chest wall shapes mostly occurred within 1 month, and the chest wall diameter stabilized 3 months after the Nuss repair.(15) All cases in our present study were followed up for at least 6 months, which was an adequate time period for monitoring PE recurrence. A correlation between bar flipping and PE recurrence can be explained as follows: The convex bars strut the depressed sternum, and the tendency of the anterior chest wall to rebound inwards causes bar flipping even before the chest wall can be remodeled. The bar still has some strength when the flip angle is < 30°. A tilted bar lacks support, which may cause PE recurrence; therefore, reciprocal causation is suggested between bar flipping and PE recurrence.

Our study shows that the bar number does not influence postoperative bar flipping or the PE recurrence rate. This may be because the number of bars placed is decided by an immediate intraoperative outcome—we would insert additional bars if one did not have enough supporting strength for lifting the concave chest wall. Based on our results, we can use an $\alpha$ of 30° as a simple cutoff value for predicting PE recurrence in patients, who may then warrant further evaluation or even a revision procedure. Although 23 of our patients with an $\alpha > 30^\circ$ had a PE recurrence, only seven of them underwent a revision Nuss procedure after evaluating aspects such as the severity of recurrence and patient’s willingness and symptoms. For patients who underwent a revision repair for PE recurrence, the Nuss procedure remains an adequate choice with good outcomes, regardless of whether the initial repair was also a Nuss procedure; this is consistent with the results from Casamassima et al.(16) We hypothesize that the repositioning of the Nuss bars in a revision procedure increases the likelihood of successfully lifting the depressed anterior chest wall and provides additional time for chest wall remodeling.

We acknowledge that this study was retrospective and was performed at a single institute. Our case numbers with a bar flipping of $\alpha > 30^\circ$ and revision cases were limited. Researchers are encouraged to use our test model to conduct more clinical studies and provide solid evidence on PE recurrence. Moreover, a longer follow-up period is still required for patients who undergo a revision Nuss procedure.

**Abbreviations**

ANOVA
One-way analysis of variance
AUC
Declarations

Availability of data and materials

The data sets used and analyzed during the current study are available from the corresponding author.

Ethics approval and consent to participate:

The authors are 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. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by the Ethics Committee of and the Institutional Review Board of the Taipei Tzu Chi Hospital, Taipei, Taiwan, ROC (IRB No: 08-X-101), and individual consent for this retrospective analysis was waived.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Informed consent was obtained from the patient for publication of chest X-ray images.

Authors’ contributions
(I) Conception and design: Yeung-Leung Cheng  
(II) Administrative support: Yeung-Leung Cheng, Yuan-Yu Hsu, I-Shiang Tzeng  
(III) Provision of study materials or patients: Yeung-Leung Cheng, Yuan-Yu Hsu  
(IV) Collection and assembly of data: Yu-Jiun Fan, Po-Cheng Lo, Bo-Chun Wei, Yeung-Leung Cheng  
(V) Data analysis and interpretation: Yu-Jiun Fan, I-Shiang Tzeng, Bo-Chun Wei, Yeung-Leung Cheng  
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Tables

Table 1

| Flipping angle | N  | cxrHlpre\(^a\) | cxrHlpost\(^b\) | ΔcxrHl\(^c\) | I index\(^d\) |
|----------------|----|----------------|-----------------|-------------|--------------|
| <10°           | 131| 3.69±0.7       | 2.66±0.4        | 1.03±0.57   | 27±10        |
| 10–19°         | 154| 3.95±0.8       | 2.77±0.4        | 1.18±0.77   | 28±12        |
| 20–29°         | 51 | 3.94±0.9       | 2.86±0.4        | 1.09±0.7    | 26±12        |
| >30°           | 23 | 3.96±1.5       | 3.46±1.3        | 0.5±0.5     | 13±9         |

\(^a\)Haller index on the preoperative chest radiograph  
\(^b\)Haller index on the postoperative chest radiograph
c \text{cxrHlpre-cxrHlpost} \\

d \text{improvement index}=(\text{cxrHlpre-cxrHlpost})/\text{cxrHlpre}

Table 2

*Multiple comparisons between the four groups (Scheffe post hoc test)*

| (I) Group | (J) Group | Mean Dif (I−J) | p-value |
|-----------|-----------|----------------|---------|
| <10°      | 10–19°    | -0.012         | 0.850   |
|           | 20–29°    | 0.009          | 0.974   |
| >30**     |           | 0.136          | <0.001  |

| 10–19°    | 20–29°    | 0.02           | 0.732   |
| >30**     |           | 0.148          | <0.001  |

| <10°      |           | 0.012          | 0.850   |
|           | 10–19°    | 0.02           | 0.732   |
| >30**     |           | 0.127          | <0.001  |

* There is statistical difference between group >30° and other groups (p<0.001)

Table 3

*Comparison of the clinical characteristics based on a grouping by 30°*
|                          | $\alpha<30^\circ$ (n=336) | $\alpha>30^\circ$ (n=23) | p-value |
|--------------------------|---------------------------|---------------------------|---------|
| Age at Nuss repair, years (mean±SD) | 23.8±7.8                   | 25±6.8                    | 0.409   |
| Sex, n (%)               |                           |                           | 0.754   |
| Male                     | 284 (85%)                 | 20 (87%)                  |         |
| Female                   | 52 (15%)                  | 3 (13%)                   |         |
| Flipping angle, degrees (mean±SD) | 12.8±6.3                 | 40.4±5.8                  | <0.001  |
| Body weight, kg (mean±SD) | 57.6±10.7                 | 63.6±11.5                 | 0.01    |
| Haller index, (mean±SD)  | 4±0.9                     | 4.4±1.8                   | 0.018   |
| Observation period, years (mean±SD) | 2.2±1.3                 | 1.9±1.6                   | 0.405   |
| BarN, n (%)              |                           |                           | 0.641   |
| 1                        | 33 (10%)                  | 2 (9%)                    |         |
| 2                        | 269 (80%)                 | 20 (87%)                  |         |
| 3                        | 34 (10%)                  | 1 (4%)                    |         |
| Scoliosis, n, (%)        |                           |                           | 0.596   |
| Yes                      | 316 (94%)                 | 21 (91%)                  |         |
| No                       | 20 (6%)                   | 2 (9%)                    |         |
| Symmetry n, (%)          |                           |                           | 0.593   |
| Yes                      | 156 (46%)                 | 12 (52%)                  |         |
| No                       | 180 (54%)                 | 11 (48%)                  |         |

BarN: the number of inserted bars in each patient

Table 4

Comparison of the slope angle and the Haller index in seven patients before and after the revision Nuss surgery

|                          | Before revision surgery | After revision surgery | p-value |
|--------------------------|-------------------------|------------------------|---------|
| Slope angle $\alpha$ (IQR), degrees | 39.6 (38.5–52)          | 10.4 (9.1–23.7)        | 0.018   |
| cxrHI (IQR)              | 3.5 (3.1–3.8)           | 2.9 (2.5–3.1)          | 0.043   |
There was a significant difference (p<0.05) in the α and HI before and after the revision Nuss procedure.