Radiologic factors related to double-bar insertion in minimal invasive repair of pectus excavatum

Ki Hwan Kim, Ki Yeol Lee, Jung Bok Lee, Kyung-Sook Yang, Jinwook Hwang, Bo Kyung Je, Hyung Joo Park

Seoul, Korea

Original article

Background: **Pectus excavatum is the most common congenital chest wall deformity, with a high incidence in live births. This study aimed to evaluate the measured factors on CT images related to the number of pectus bars for surgical correction.**

Methods: **A total of 497 patients who had undergone minimally invasive repair between April 2007 and July 2011 were classified into single-bar (*n*=358) and double-bar (*n*=139) insertion groups. We measured eight distinct distances and one angle on CT scans to reflect quantitative assessment. Univariate analysis and multivariate logistic regression analysis were performed to detect statistically significant association between radiologic measurements and the pectus bars required.**

Results: **After adjusting for age and gender, the transverse distance (T), the transverse distance of the depression area (A), the inclined distance of the depression area (B), the AP distance of the depression area (C), the depression angle (G), and the eccentric distance of deformity (E) were significantly correlated with double-bar insertion. The regression model showed that age (*P*<0.0001), gender (*P*<0.0001), depression angle (G) (*P*<0.0001), direction of the depression (DD) (*P*<0.0001) and depression depth (D) (*P*<0.0001) were significantly associated with double-bar insertion.**

Conclusion: **CT scan provides useful factors which can be of assistance in predicting the number of pectus bars for the surgical correction of pectus excavatum.**

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Key words: **computed tomography; Nuss procedure; pectus excavatum**

Introduction

Pectus excavatum is the most common congenital chest wall deformity, with an incidence of 23 per 10 000 live births.[1] The majority of patients with pectus excavatum are diagnosed within the first two years of life.[2] With the introduction of the Nuss procedure, pectus excavatum can be corrected with excellent long-term effects,[3] and this procedure is becoming widely utilized. When minimally invasive repair of pectus excavatum was first introduced, it was usually performed with a single bar; double-bars were inserted in limited cases of broad or long depressions. However, currently, when a single bar is insufficient, surgeons do not hesitate to perform double-bar corrections, especially in adults.[4,5]

Radiologic examinations can evaluate the severity of pectus excavatum and determine whether surgical corrections are needed or not.[6-8] Chest computed tomography (CT) is widely used as a radiologic tool in patients with pectus excavatum and allows clinicians to assess the pectus excavatum. The quantitative approach using CT scan allows surgeons to plan surgical operations objectively, and variable measurements were also widely used. But until now, there have been hardly any studies conducted to evaluate the associations between radiologic factors and double-bar insertion in surgical correction.

The aim of the present study was to evaluate the relationship between measured factors on CT images and the number of pectus bars required.

Methods

Patients

The institutional review board approved this study and the

Author Affiliations: Department of Radiology, Korea University College of Medicine, Ansan, Korea (Kim KH, Lee KY, Je BK); Department of Clinical Epidemiology and Biostatics, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea (Lee JB); Department of Biostatistics, Korea University College of Medicine, Seoul, Korea (Yang KS); Department of Thoracic Surgery, Korea University College of Medicine, Ansan, Korea (Hwang J); Department of Thoracic and Cardiovascular Surgery, Seoul St. Mary's Hospital, the Catholic University of Korea, Seoul, Korea (Park HJ)

Corresponding Author: Ki Yeol Lee, MD, PhD, Department of Radiology, Korea University Ansan Hospital, Korea University College of Medicine, 516, Gojan 1-dong, Danwon-gu, Ansan-si, Gyeonggi-do 425-707, Korea (Tel: +82-31-412-5228; Fax: +82-31-412-5226; Email: Kiylee@korea.ac.kr)

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requirement for informed consent was waived. From April 2007 to July 2011, a total of 497 patients (age range, 2-39 years; mean age, 9.8 years), who underwent minimally invasive repair for pectus excavatum, were enrolled in this retrospective study. The male to female ratio was 4.8 (412 male; 85 female). Surgeons estimated the number of pectus bars required based on preoperative CT scans and made final decisions in the operating room. Single-bar insertion was done for 358 (358/497, 72.0%) patients. Four patients underwent repair with three bars, but they were included in the double-bar insertion group. Therefore, 139 patients (139/497, 28.0%) were classified as the double-bar insertion group. All patients underwent multidetector computed tomography (MDCT) two weeks prior to surgery. Postoperative CT scans were also taken to evaluate the results of surgical correction on postoperative day five.

Operative data and complications were also extracted from electronic medical records. The number of inserted pectus bars was checked by operative data. We compared the incidence of complications including: pneumothorax and pleural effusion requiring drainage, bar displacement, hematoma requiring incision and drainage, and skin infection in single- and double-bar insertion groups.

Image acquisition

MDCT images were obtained using a commercial 64-channel MDCT (Brilliance 64; Phillips, Cleveland, OH, USA) with scanners set at 120 kVp and 35-50 mAs, automatic tube current modulation with a pitch of 0.673, and collimation of 40-mm (64×0.625) without intravenous contrast material. The rotation time was 0.75 seconds. Images were reconstructed as 5.0 mm thick sections using a soft tissue algorithm.

Measurement of factors and indices

Two readers reviewed CT images at the same time and the axial image with the most depression was selected by consensus. To quantify the anatomical morphology of the chest wall, we made 8 distance measurements and one angle measurement (Fig. 1). These measurements included maximum transverse internal thoracic distance (transverse distance, T); minimum anteroposterior (AP) distance between the deepest point of the anterior chest wall and the anterior margin of the vertebral column (vertical distance, V); the distance between the first horizontal line passing the deepest point of the anterior chest wall and the second horizontal line passing the highest point of the anterior chest wall (depression depth, D); the angle calculated by the first line between the deepest point of the anterior chest wall and the highest point of the right anterior chest wall, and the second line between the deepest point of the anterior chest wall and the highest point of the left anterior chest wall (depression angle, G).

We measured 3 linear distances using the two highest points of the bilateral chest walls: the horizontal distance (transverse distance of the depression area, A), the shortest distance (inclined distance of the depression area, B), and the AP distance (AP distance of the depression area, C). The transverse distance of the depression area (A) and the inclined distance of the depression area (B) represent the width of the depression area.

Whenever the deepest depression point was not located in the center of the sternum, the pectus excavatum was classified as an "asymmetric type". To evaluate the degree of asymmetry, the transverse distance between the deepest point of the anterior chest wall and the center of the vertebral column (eccentric distance of deformity, E) was measured, and the direction of the deepest point of the depression (direction of the depression, DD) was also assessed. The vertical length of the sternum (sternal length, L) was calculated by multiplying slice thickness by the number of slices, from the top of the manubrium to the xiphisternal junction. The distance measurements

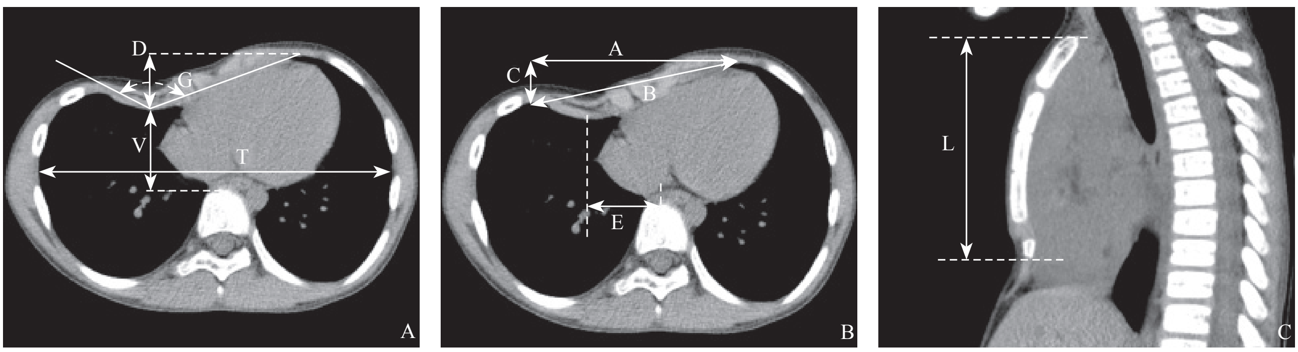

Fig. 1. Eight distances and one angle were measured as factors on multidetector computed tomography scans. **A&B**: transverse distance (T), vertical distance (V), depression depth (D), depression angle (G), transverse distance of the depression area (A), inclined distance of the depression area (B), AP distance of the depression area (C), and eccentric distance of deformity (E) were measured on axial image at the most depressed level; **C**: Sternal length (L) was calculated by multiplying slice thickness and the number of slices from the top of the manubrium to the xiphisternal junction.

Table 1. Univariate analysis of patient characteristics and factors measured on CT between single-bar and double-bar insertion groups

Factors	Single-bar (*n*=338)		Double-bar (*n*=139)		*P* value
	Mean	SD	Mean	SD	
Age (y)	7.25	5.72	16.29	6.45	<0.0001
Gender					0.0551
Male	304	84.92	108	77.70	
Female	54	15.08	31	22.30	
Factors measured on MDCT scan					
Transverse distance (T) (mm)	193.61	35.27	239.12	27.70	<0.0001
Vertical distance (V) (mm)	47.67	18.09	59.12	16.46	<0.0001
Depression depth (D) (mm)	22.09	9.40	25.58	10.69	0.0004
Transverse distance of the depression area (A) (mm)	101.42	25.50	140.07	26.33	<0.0001
Inclined distance of the depression area (B) (mm)	102.01	26.89	140.59	26.07	<0.0001
AP distance of the depression area (C) (mm)	4.39	6.42	8.61	6.18	<0.0001
Depression angle (G)	135.96	15.06	145.45	13.18	<0.0001
Eccentric distance of deformity (E) (mm)	3.53	7.05	14.18	14.82	<0.0001
Sternal length (L) (mm)	106.23	33.41	141.55	40.22	<0.0001

MDCT: multidetector computed tomography; AP: anteriorposterior; SD: standard deviation.

were recorded in millimeters, and the angle was recorded in degrees. Haller index, the ratio (T/V), was measured on preoperative and postoperative CT scans, respectively.

Statistical analysis

In univariate analysis, the data were summarized with mean and standard deviation for continuous factors. Further, frequency and percentage, for categorical factors, were demonstrated using the chi-square test and Student's *t* test. Least squares LS means were also calculated on the fitted model of the generalized linear model to adjust for age and gender. Statistical significance was reached when the corresponding *P* value was less than or equal to 0.05, based on hypothesis testing.

By utilizing the measured factors, multivariate logistic regression with 500 bootstrap samples was performed in order to create a logistic regression model. A backward elimination approach allowed a regression equation model in which the choice of logistic regression factors was made. Hosmer-Lemeshow's goodness-of-fit test was used for model calibration.

The receiver operating characteristic (ROC) validation method was used to test the multivariate logistic model. The optimal cut-off was defined as that which maximizes Youden's index (J=sensitivity+specificity−1). For statistical analysis, SAS 9.13 (SAS Institute, Cary, NC, USA) was used.

Results

The mean Haller index was 4.4±1.5 on preoperative CT scans and reduced to 2.58±0.38 on postoperative CT scans. In the single- and double-bar insertion groups, the mean age was 7.25 and 16.29, respectively (P<0.0001). All measured factors were different between the two groups (P<0.05), but age and gender may serve as confounding factors (Table 1). After adjusting for age and gender, the transverse distance (T), the transverse distance of the depression area (A), the inclined distance of the depression area (B), the AP distance of the depression area (C), the depression angle (G), and the eccentric distance of deformity (E) were significantly correlated with double-bar insertion (P<0.05) (Table 2).

Table 2. Univariate analysis of factors measured on CT between single-bar and double-bar insertion groups after adjusting for age and gender

Factors	Single-bar (*n*=338)	Double-bar (*n*=139)	*P* value
Transverse distance (T)	202.05	206.53	<0.0001
Transverse distance of the depression area (A)	106.61	117.11	<0.0001
Inclined distance of the depression area (B)	108.56	117.32	<0.0001
AP distance of the depression area (C)	5.13	8.20	<0.0001
Depression angle (G)	135.96	145.45	<0.0001
Eccentric distance (E)	3.11	13.08	<0.0001

CT: computed tomography; AP: anteriorposterior.

Table 3. Distributions of direction of the depression in patients with pectus excavatum on multidetector computed tomography

Direction of the depression (DD)	Single-bar (*n*=358)	Double-bar (*n*=139)	*P* value
Symmetry (*n*=320)	262	58	<0.0001
Asymmetry (*n*=177)	96	81	-
Left-sided depression (*n*=36)	26	10	<0.0001
Right-sided depression (*n*=141)	70	71	-

Of the 497 patients, 177 (35.6%) displayed asymmetric pectus excavatum (Table 3). The frequency of double-bar insertion was higher in patients with asymmetric pectus excavatum (36/177, 45.8%) than in patients with symmetric pectus excavatum (58/320, 18.1%) (P<0.0001). Among asymmetric pectus

Table 4. Multivariate logistic regression model conducted using characteristics of patients and multiple factors measured on CT scans

Variables	Odds ratio (95% CI)	*P*-value
Age	1.195 (1.135-1.259)	<0.0001
Gender	0.261 (0.121-0.559)	0.001
Depression angle (G)	1.084 (1.049-1.120)	<0.0001
Direction of the depression (DD)	0.121 (0.064-0.227)	<0.0001
Depression depth (D)	1.085 (1.040-1.131)	<0.0001

CT: computed tomography; CI: confidence interval.

Table 5. Comparison of postoperative complications between single-bar and double-bar groups

Variables	Single-bar group (*n*=359)	Double-bar group (*n*=139)	*P*-value
Pneumothorax	2 (0.6)	7 (5.0)	0.007
Pleural effusion	16 (4.5)	17 (12.2)	0.003
Displacement	5 (1.4)	3 (2.2)	0.405
Hematoma	0 (0)	2 (1.4)	-
Skin infection	5 (1.4)	5 (3.6)	0.151
Sum	27 (7.8)	32 (24.5)	

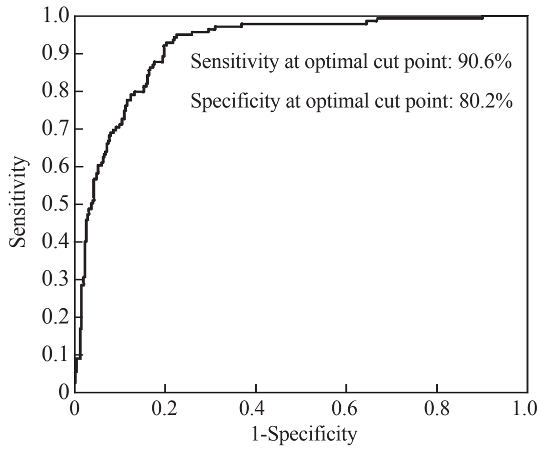

Fig. 2. Receiver operator characteristics curve of a multivariate logistic regression model for double-bar insertion. As compared with the Haller index (area under the curve, AUC=0.542), a multivariate logistic regression model (AUC=0.915, *P*<0.0001) showed a superior performance in discriminating between single-bar insertion and double-bar insertion.

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excavatums, most patients had right-sided asymmetry (80.0%, 141/177). Patients with right-sided asymmetry (50.3%, 71/141) tended to undergo operations using double-bar insertion more frequently than patients with left-sided asymmetry (27.8%, 10/36) (*P*<0.0001).

Multivariate stepwise logistic regression analysis with bootstrapping was performed for all factors including CT measurements, gender and age. Five factors were mainly associated with the requirements for double-bar insertion (Table 4); age, gender, depression angle (G), the direction of the depression (DD) and depression depth (D). The performance of the multivariate model was evaluated by a ROC curve (Fig. 2). The value of area area under the curve (AUC=0.915) was significantly different from 0.5 (*P*<0.0001) and showed a more significant performance than the Haller index (AUC=0.542). The cut-off value, corresponding to the maximal Youden's index, was 0.708; sensitivity and specificity were calculated to be 90.6% and 80.2%, respectively.

Postoperative complications, which were present in both groups, are shown in Table 5. The complication rate was higher in the double-bar group (24.5%) than in the single-bar group (7.8%) (*P*<0.0001). Pleural effusion, requiring drainage catheter insertion, was the most common complication in both groups. Bar displacement occurred in eight patients: five in the single-bar group and three in the double-bar group. All eight patients with bar displacement underwent reoperation. Wound hematoma occurred in two of the patients with double-bar insertion, and surgical removal was performed.

Discussion

Surgical repair of pectus excavatum is a universally accepted treatment. In determining the need for repair of pectus excavatum, the Haller index, with a cut-off value of 3.25, has been used traditionally.[6] Since the development of the Haller index, a variety of other indices has been designed; however, the roles of these conventional indices are limited to determining whether or not to perform surgical repair.[7-12]

In utilizing a minimally invasive procedure for the repair of pectus excavatum, surgeons determine the number of pectus bars required for surgery. Although surgical methods or surgeon's preference may affect the use of double-bar insertion, the morphological characteristics of patients with pectus excavatum are also one of the factors that affect the surgeons' decisions to perform double-bar correction rather than single one. These radiologic data are objective tools for evaluating morphology of pectus excavatum and would allow for the surgeon to make a correction plan. However, there is no previous study that elaborates upon what kinds of radiologic factors are associated with the number of bars needed to be used for correction.

As shown in previously published reports, the presence of a wide variety of morphological phenotypes is a characteristic of pectus excavatum.[5,13,14] In quantitative morphology assessment, the patient's chest wall size independently affects the morphology of pectus excavatum. As the chest wall size is largely determined on patient's age and gender, statistical analysis should be adjusted for patient's age and gender.

The severity of pectus excavatum was traditionally evaluated by depression depth; however, our study showed that other radiologic factors may serve as parameters, which were associated with double-bar insertion. After adjusting for age and gender, the following factors were found to be significantly related with the bar number (single- or double-bar): the transverse distance (A), the inclined distance (B) and the depression angle (G). It was found that the greater the width of the depression area of pectus excavatum was, the more frequently double-bar insertion was used. Therefore, we suggest that the width of the depression area be an important factor for evaluating the difficulty of surgical repair.

The AP distance of the depression area (C) was higher in double-bar insertion than in single-bar insertion. Also, the eccentric distance of deformity (E), which is an alternative way to evaluate asymmetry, was also significantly different between the two groups. The higher chance of double-bar insertion in patients with asymmetry was revealed in our study. Therefore the asymmetry of pectus excavatum may serve as a significant challenge when performing surgical operation, and surgical techniques have been developed to overcome asymmetry.[14,15]

Most patients with asymmetric pectus excavatum had right-sided asymmetry, and double-bar insertion was performed more frequently for the patients with right-sided asymmetry. This result suggests that pectus excavatum with right-sided asymmetry is more severe. In previous studies, the location of the heart, toward the back of the left chest wall, has been considered to play a role in preventing left-sided depressions.[16] This may be the reason why right-sided asymmetry is more common and double-bar insertion is frequently performed in right-sided asymmetry than in left-sided asymmetry.

Age was an independent factor for determining the number of pectus bars. This finding is consistent with previous studies that mentioned the need for double-bar insertion in late adolescents and adults.[4,17,18] Yoon et al[18] wrote that double-bar insertion might be more stable for late adolescent and adult patients. The chest wall size of adults is larger than that of children, so it is relatively difficult to correct pectus excavatum via single-bar insertion. A patient's age is also a risk factor for asymmetrical transformation of pectus excavatum.[19] As mentioned above, asymmetry increases the difficulty of surgical repair. Thus, early surgical correction, prior to asymmetrical transformation, can aid in avoiding double-bar insertion.

Our study had several limitations. Firstly, this is a retrospective study based on a limited number of institutions. Although the patients were restricted to two institutions, a large number of patients could overcome this problem. Secondly, the duration between follow-ups is not sufficient enough to have an impact on the long-term success rate of the operations conducted in our institutions. Therefore, more studies will be necessary to conduct a longitudinal follow-up study targeting the subjects who underwent minimally invasive repairs of pectus excavatum. Thirdly, radiation exposure has been problematic when using CT scanning for pectus excavatum; however, this can be controlled by utilizing MRI, if available, or by adopting an iterative reconstruction technique. Finally, the majority of the decisions for the correction of pectus excavatum depend on surgeons themselves, and the definition of "complete correction" is variable. Thus, the result of this study can be considered as one of many factors that should be referred to when surgeons make the decisions on the number of pectus bars.

In conclusion, age, gender, depression angle (G), the direction of depression (DD), and depression depth (D) were associated with double-bar insertions. We believe that our results can provide some reference data for the surgeons who want to have objective guidelines for their preoperative planning on the number of bars. The associations between radiologic factors and double-bar insertions should be validated with the future prospective clinical studies in more institutions.

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Ethical approval: The hospital's institutional review board approved this study.

Competing interest: None declared.

Contributors: KKH and LKY proposed the study. KKH wrote the main body of the article under the supervision of LKY and PHJ. LJB and YKS analyzed the data. HJ and JBK provided advice on medical aspects. KKH and PHJ contributed equally to this paper.

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