의학석사 학위논문

Classification of pectus excavatum according to morphologic parameters measured in chest computed tomography

흉부 전산화 단층 촬영으로 얻은 형태학적 지표를 기반으로 한 누두흉의 분류법

2015 년 2 월

서울대학교 대학원

의과대학 의학과

최 진 호

Abstract

Introduction: The present classification systems of pectus excavatum are based on subjective morphology. We herein describe a classification system of pectus excavatum based on objective data and validate the clinical relevance of the new classification.

Methods: Patients who underwent surgical repair of pectus excavatum without a history of chest surgery were included in this study. Classification was performed by hierarchical clustering of morphologic parameters obtained from chest computed tomography, including the pectus index, asymmetry index, flatness index, sternal torsion angle, and angle of Louis. Correlations among parameters were analyzed, and the clinical relevance of the suggested classification system was verified.

Results: In total, 230 patients who underwent operations from

January 2001 to August 2013 were included in the study. The patients were classified into two major groups: the typical group (Group I, n = 197) and atypical group (Group II, n = 33). Group I was divided into three minor groups: the symmetric group (Ia, n = 82), asymmetric proper group (Ib, n = 108), and asymmetric with flat sternum group (Ic, n = 7). Group II was classified into four minor groups: the asymmetric with doubly distorted sternum group (IIa, n = 8), asymmetric with severe sternal torsion group (IIb, n = 8), reverse asymmetric group (IIc, n = 16), and extremely depressed group (IId, n = 1). The asymmetry of the pectus excavatum was associated with the sternal torsion angle ($p < 0.0001$, $R = 0.625$) and inversely associated with the angle of Louis ($p = 0.013$, $R = -0.163$). Scoliosis was more common in Group IIa than Ia ($p = 0.0008$, odds ratio [OR] =10.5, 95% confidence interval [CI] = 1.7–63.6), and multiple bar insertion was necessary more frequently in Groups Ic ($p = 0.001$, OR = 34.9, 95% CI = 3.9–310.1) and IIb ($p = 0.007$, OR = 22.7, 95% CI = 2.3–223.6) compared with Group Ia.

Conclusions: This new classification produced two major groups with typical and atypical morphology and seven minor subgroups. The classification was clinically relevant in that specific subgroups were associated with scoliosis and with the need for multiple bar insertion.

주요어: Pectus excavatum, Classification

학 번: 2010 -21835

목 차

표 및 그림 목록

Introduction

Pectus excavatum is characterized by a depression of the anterior chest wall and is suggested to be caused by overgrowth of the costal cartilage. The prevalence of pectus excavatum reportedly ranges from 1 in 300 to 1 in 1000 live births and is higher in male than female patients. The deformity usually appears during the first year of life and may become more prominent as the patient develops (1, 2). Most affected patients are asymptomatic, but some may present with cardiopulmonary symptoms (3). Despite the absence of presenting symptoms, many patients develop psychological problems due to a distorted body image, and therefore seek medical attention (4, 5).

The Ravitch procedure (6) and Nuss procedure (7) are commonly accepted surgical correction techniques for pectus excavatum. The Ravitch procedure, which has been adopted as the standard surgical approach for more than half a century, involves the removal of the costal cartilage followed by correction and stabilization of the sternal position. The Nuss procedure is a two-stage approach involving placement of a convex metal plate behind the sternum without resection of the costal cartilage followed by removal of the plate 2–4 years after plate placement.

Although there are concerns regarding unnecessary exposure to radiation (8), chest computed tomography (CT) has been a primary tool for preoperative assessment. Parameters such as the pectus index (PI), asymmetry index (AI), flatness index (FI), and sternal torsion angle (STA) can be measured to evaluate the morphology of chest wall deformities (9). Asymmetry, which has been a major cause of unsatisfactory correction outcomes, can be better addressed by chest CT than by physical examination (10). CT scans may also reveal features such as cardiac displacement or compression, atelectasis, or airway compression and other associated anomalies.

Many studies on pectus excavatum have focused on the optimal procedure for corrective surgery (11), optimal age of repair (1, 2, 12), or whether cardiopulmonary function is improved after correction (3, 13). On the other hand, less attention has been paid to classification systems of pectus excavatum. Although several studies have suggested such classification systems (10, 14, 15), none has gained popularity among clinicians. Thus far, these classification systems have suffered from unclear definitions and a lack of criteria for each type; most importantly, they are based only on subjective morphologic findings.

The present study was performed to describe and suggest the use of a new classification system based on objective parameters. The authors hypothesized that this new classification may reveal new types of pectus excavatum and that clinical outcomes may differ among groups according to the new classification.

Materials and Methods

A retrospective review of medical records and preoperative chest CT scans was performed for patients with pectus excavatum who underwent surgical repair, by either the Ravitch procedure or Nuss procedure, in our institution. Patients who had undergone sternotomy or previous corrective surgery for the chest wall, those who had not undergone preoperative CT, and those whose chest wall deformity was of the combined pectus carinatum type were excluded from our study.

Five representative parameters, namely the PI, AI, FI, STA, and angle of Louis (AoL), were measured from a slice presenting the most depressed point on a preoperative chest CT scan and/or a simple lateral chest radiograph. Definitions of the above-mentioned parameters are as follows (Fig. 1): (1) PI = (longest lateral distance of chest wall) / (shortest anteroposterior distance between most depressed point and vertebra); (2) AI = (longest anteroposterior distance of left chest wall) / (longest anteroposterior distance of right chest wall); (3) FI = (longest lateral distance of chest wall) / (longer of the longest anteroposterior distance of the left or right chest wall); (4) STA = angle between sternum and horizontal line, with a positive value indicating counterclockwise rotation of the sternum and a negative value indicating clockwise rotation; and (5) AoL = angle between manubrium and body of sternum on sagittal image.

Correlations among parameters were evaluated by Pearson's correlation analysis to obtain a further descriptive explanation of the proposed classification system. The classification system was established by hierarchical clustering using the five representative parameters as clustering variables with the average-linkages-between-group method. The number of clusters was determined by ensuring that no cluster included fewer than five cases. Age differences among groups were compared by the Kruskal-Wallis test. For multivariate analysis, a Firth logistic regression model was adopted to verify the clinical implications of the new classification system. Statistical analysis was performed using SPSS 18.0 for Windows and SAS

9.3 for Windows.

Results

A total of 296 patients underwent corrective surgery for pectus excavatum in our institution from January 2001 to August 2013. After excluding 66 patients with a history of sternotomy (n = 8) or corrective surgery (n = 24), who had not undergone preoperative CT (n = 32), or whose chest wall deformity was of the combined pectus carinatum type (n = 2), data from 230 patients were obtained.

The median patient age was 6.0 years (range, 2.1–30.1 years), and the group exhibited male predominance (82.6%). The patients were initially treated with either the Nuss procedure (n = 197) or Ravitch procedure (n = 33). Comorbidities included scoliosis (n = 17), connective tissue disease (n = 7), Marfan syndrome (n = 5), Loeys-Dietz syndrome (n = 1), and Ehlers-Danlos syndrome (n = 1). Chest CT findings other than chest wall anomalies were congenital cystic adenomatoid malformation (n = 3), pericardial cyst (n = 1), and dextrocardia (n = 1).

Mean values for the selected parameters were as follows. (1) PI = 4.91 ± 2.85 (range, 2.06–41.04); (2) AI = 1.02 ± 0.07 (range, 0.85–1.28) (4) FI = 1.75 ± 0.14 (range, 1.30–2.25); (4) STA = 7.11 ± 12.09 (range, −38.00 to 41.70); (5) and AoL = 167.22 ± 7.05 (range, 142.40–188.00). Correlation analysis revealed significant correlations between PI and FI (correlation coefficient [R] = 0.389, $p < 0.001$], PI and AoL ($R = -0.134$, $p = 0.042$), and AI and STA ($R = 625$, $p < 0.001$).

Through hierarchical clustering using the above-mentioned parameters, the 230 patients were first divided into five groups comprising 197, 16, eight, eight, and one patients (Fig. 2A). The group comprising 197 patients was the typical major group (Group I), and the other patients constituted the atypical major group (Group II) as a whole. Group I was selectively subclassified in the same manner into three groups (Fig. 2B). As a result, hierarchical clustering resulted in two major groups: the typical group (Group I, n = 197), which was subdivided into three minor groups, and the atypical group (Group II, n = 33), which was subdivided into four minor groups. The three minor groups of Group I were the symmetric group (Ia, n = 82), asymmetric proper group (Ib, n = 108), and asymmetric with flat sternum group (Ic, n = 7). The four minor groups of Group II were the asymmetric with doubly distorted sternum group (IIa, n = 8), asymmetric with severe sternal torsion group (IIb, n = 8), reverse asymmetric group (IIc, n = 16), and extremely depressed group (IId, n = 1). The mean values of the five parameters, median age, and representative images of each group are shown in Tables 1 and 2. There were no significant differences in median age among the groups (p = 0.175).

We then evaluated the clinical relevance of the new classification system (Table 3). We analyzed the association of scoliosis (n = 17; four each in Groups Ia and IIa, one each in Groups IIc and IId, and seven in Group Ib) with the new classification system, age, sex, comorbidity of connective tissue disorders such as Marfan syndrome, and the selected parameters. Compared with Group Ia, the symmetric group, scoliosis was more common in Group IIa, the asymmetric with doubly distorted sternum group (p = 0.0076, odds ratio [OR] = 10.5, 95% confidence interval [CI] = 1.7–63.6). A higher PI was significantly associated with scoliosis (p = 0.002, OR = 1.5, 95% CI = 1.2–1.9). The risk of developing scoliosis was not significantly associated with sex, coexisting connective tissue disorders, or parameters other than PI. However, scoliosis was marginally associated with age (p = 0.059, OR = 1.071, 95% CI = 1.0–1.2). Among patients who underwent initial correction with the Nuss procedure (n = 197), we analyzed the association of adopting a parallel bar technique (n = 15; two each in Groups Ia and IIb, eight in Group Ib, and three in Group Ic) and bar rotation after surgery (n = 10; two in Group Ia, five in Group Ib, and one each in Groups IIb, IIc, and IId) with the new classification system, age, sex, and the selected parameters. Compared with Group Ia, the parallel bar technique was more frequently adopted in Group Ic, the asymmetric with flat sternum group (p = 0.0014, OR = 34.9, 95% CI = 3.9–310.1), and Group IIb, the asymmetric with severe sternal torsion group (p = 0.0074, OR = 22.7, 95% CI =

2.3–223.6). Parallel bar modification was associated with age ($p = 0.0001$, OR = 1.2, 95% CI = 1.1–1.3), STA ($p = 0.009$, OR = 1.1, 95% CI = 1.0–1.2), and AoL ($p = 0.017$, OR = 1.1, 95% CI = 1.0–1.2). Bar rotation after the Nuss procedure was not associated with the classification, sex, or the selected study parameters, but was associated with age ($p = 0.031$, OR = 1.1, 95% CI = 1.0–1.2).

Discussion

Several classification systems for pectus excavatum have been suggested (10, 14, 15), but no consensus has been established. Some of these classification systems are used as references in describing the morphologic features of pectus excavatum in individual cases. However, they are not widely adopted in scientific studies of pectus excavatum performed by authors other than those who have suggested their own classification system. The main reason that none of the previous classification systems is in common use is that all are based on subjective morphologic findings. These classification systems may exhibit poor reproducibility because subjective descriptions of morphology may vary among observers, e.g., acute or diffuse type, symmetric or asymmetric type, etc.

Thus, we herein suggest a scientific classification system with reproducibility. To supplement the shortcomings of previous classification systems, this new classification system is solely based on objective parameters. It is derived from hierarchical clustering analysis using objective parameters derived from preoperative chest CT and/or simple lateral chest radiography.

Hierarchical clustering is a method commonly used to build a taxonomy of classes. It begins with individual objects, which are iteratively merged into larger clusters with objects or clusters at closest vector distance until a final all−inclusive cluster is established. The technique is used to discover structure in a data set that has no labeled pattern (16). The number of clusters is flexibly determined according to the level of granularity. In this study, we intended that each cluster should have distinguishable features and should include at least five cases. However, Group IId comprised a single case because it was an outlier due to an extreme PI value. The patients in this study were clustered into five groups. One cluster was the typical major group, and the other four were subgroups of the atypical minor group. The typical major group was selectively subclassified because further classification into six or seven groups only resulted in separation of the atypical major group into smaller groups. Through hierarchical clustering, 230 cases were classified into seven subgroups as explained above.

Some of the results of the correlation analysis between parameters support the descriptive features of each subgroup. STA and AI are the core indices differentiating many of the subgroups in this classification. Among Groups Ib, Ic, IIa, and IIb, the severity of counterclockwise rotation of the sternum was associated with the severity of asymmetry toward the right side. In Group IIc, clockwise rotation of the sternum was associated with asymmetry toward the left side, which was defined as reverse asymmetry. This correlation has also been suggested in previous studies (1, 10). In a study by Yoshida et al. (1), groups of patients of different ages were further divided according to the severity of sternal torsion. The authors found a correlation between AI and STA and suggested that STA torsion may progress in a counterclockwise direction as the patient grows. Although no significant age difference was demonstrated among the newly classified groups, the patients in the reverse asymmetric group and symmetric group tended to be younger. Other than the STA, a smaller AoL was more closely associated with larger PI in the asymmetric with doubly distorted sternum group and the asymmetric with severe torsion group compared with the other groups.

This symmetric/asymmetric classification is in accordance with Cartoski's classification system (10). However, because of vague cutoff line between localized/diffuse types and short length/long length types, we could only assume that some of our group would be classified as the localized type or long length type. Because Cartoski, et al. defined severe/mild sternal torsion using a cutoff value of 30 degrees, asymmetric groups in this new classification system could be categorized. The definition of asymmetry in Park's classification system (14) differs from ours. Park, et al. defined symmetry as colocation of the center of the sternum and the center of the depression. The unbalanced type in their classification system is the asymmetric group in our classification. Because the major obstacle of corrective surgery is more often the different heights of the bilateral chest walls than the point of deepest depression, the definitions used in the classification system presented here are more clinically practical. Additionally, the reverse asymmetric group has never been categorized by any classification systems. It is a new type discovered by our classification system.

In contrast to previous classifications, this new classification system was found to have clinical implications. Group IId comprised only one patient and was excluded from the analysis after consultation with a statistician because it distorted the proper analysis (i.e., this group has either 0% or 100% incidence). In this particular patient, who was 12 years old, it was difficult to differentiate whether scoliosis had caused exaggeration of the high PI or severe depression had eventually caused scoliosis over a long period of uncorrected pectus excavatum. The findings concerning scoliosis in this study are in accordance with those of previous studies that demonstrated that the incidence of scoliosis is higher in patients with pectus excavatum with more severe depression, greater asymmetry, or older age (17, 18). The use of the parallel bar technique was more common in the asymmetric with flat sternum group and asymmetric with severe sternal torsion group than in the symmetric group. The asymmetric with flat sternum group seemed to represent cases categorized as Grand Canyon type or long length type in previous classification systems (10, 14). Because all parameters excluding AoL are obtained from two-dimensional images of the horizontal view, this new classification system has an inevitable weakness in differentiating such types. These types, however, which constitute 0.6% in Park's classification system, are too rare to group as a cluster with a significant number of cases. Because age is associated with the use of the parallel bar technique, with bar rotation after the Nuss procedure, and possibly with scoliosis, surgical correction at an earlier age may be justified for patients in certain groups. Additionally, surgeons can predict a higher possibility of a poorer aesthetic outcome after correction in some groups with asymmetry because severe asymmetry is the major obstacle to pectus excavatum repair.

The limitations of this study are as follows. First, it was a retrospective study of patients who underwent surgical correction. No patients with milder forms of pectus excavatum were included, such as those who did not visit a hospital at all or those who were being followed up without corrective surgery. Second, like previous classifications, we failed to suggest a clear cut-off line among the groups. However, new cases can be classified by adding them to this data set of 230 patients and performing hierarchical clustering in the same manner. Third, the total number of patients may have been insufficient to classify smaller groups or to verify different ages among the groups. Similarly, the number of events may have been too small to analyze the clinical implications of the classification system, and the number of cases included in some groups may have been insufficient for proper analysis. Finally, the criteria for the new classification system do not include certain features that could not be quantified using one of the parameters employed here.

Despite these limitations, the present study is meaningful because it is the first attempt to classify pectus excavatum according to objective parameters, and it demonstrated clinically important differences among various groups. Additionally, to the best of our knowledge, this is the first study to reveal correlations among whole selected parameters of pectus excavatum, which support the descriptions of our new classification system. We expect that our new classification system can serve as a cornerstone for the scientific classification and evaluation of pectus excavatum. Further studies with larger numbers of cases would strengthen and further develop our new classification system.

References

1. Yoshida A, Uemura S, Yamamoto M, Nouso H, Kuyama H, Muta Y. Correlation of asymmetric chest wall deformity and growth in patients with pectus excavatum. J Pediatr Surg. 2013;48(4):771-5.

2. Hyung Joo Park S-WS, Jae-Kil Park, Jae Jun Kim, Hyun Woo Jeon and Young-Pil Wang. How early can we repair pectus excavatum: the earlier the better? Eur J Cardiothorac Surg. 2012;42(4):6.

3. Maagaard M, Tang M, Ringgaard S, Nielsen HH, Frokiaer J, Haubuf M, et al. Normalized cardiopulmonary exercise function in patients with pectus excavatum three years after operation. Ann Thorac Surg. 2013;96(1):272-8.

4. Kelly RE, Jr., Cash TF, Shamberger RC, Mitchell KK, Mellins RB, Lawson ML, et al. Surgical repair of pectus excavatum markedly improves body image and perceived ability for physical activity: multicenter study. Pediatrics. 2008;122(6):1218-22.

5. Hadolt B, Wallisch A, Egger JW, Hollwarth ME. Body-image, self-concept and mental exposure in patients with pectus excavatum. Pediatr Surg Int. 2011;27(6):665-70.

6. Ravitch MM. The operative treatment of pectus excavatum. J S C Med Assoc. 1955;51(7):244-9.

7. Nuss D. Minimally invasive surgical repair of pectus excavatum. Semin Pediatr Surg. 2008;17(3):209-17.

8. Rattan AS, Laor T, Ryckman FC, Brody AS. Pectus excavatum imaging: enough but not too much. Pediatr Radiol. 2010;40(2):168-72.

9. Zahir U. Sarwar RD, Stephen C. O'Connor. Pectus excavatum: current imaging techniques and opportunities for dose reduction. Semin Ultrasound CT MR. 2014;35(4):374-81.

10. Cartoski MJ, Nuss D, Goretsky MJ, Proud VK, Croitoru DP, Gustin T, et al. Classification of the dysmorphology of pectus excavatum. J Pediatr Surg. 2006;41(9):1573-81.

11. Nasr A, Fecteau A, Wales PW. Comparison of the Nuss and the Ravitch procedure for pectus excavatum repair: a meta-analysis. J Pediatr Surg. 2010;45(5):880-6.

12. Papandria D, Arlikar J, Sacco Casamassima MG, Ortega G, Salazar JH, Zhang Y, et al. Increasing age at time of pectus excavatum repair in children: emerging consensus? J Pediatr Surg. 2013;48(1):191-6.

13. Jayaramakrishnan K, Wotton R, Bradley A, Naidu B. Does repair of pectus excavatum improve cardiopulmonary function? Interact Cardiovasc Thorac Surg. 2013;16(6):865-70.

14. Park HJ, Lee SY, Lee CS, Youm W, Lee KR. The Nuss procedure for pectus excavatum: evolution of techniques and early results on 322 patients. Ann Thorac Surg. 2004;77(1):289-95.

15. Saxena AK, Willital GH. Valuable lessons from two decades of pectus repair with the Willital–Hegemann procedure. J Thorac Cardiovascular Surg. 2007;134(4):871-6.

16. Abbas OA. Comparison between data clustering algorithms. Int Arab J Inf Techn. 2008;5(3):6.

17. Hong JY, Suh SW, Park HJ, Kim YH, Park JH, Park SY. Correlations of adolescent idiopathic scoliosis and pectus excavatum. J Pediatric Orthop. 2011;31(8):870-4.

18. Wang Y, Chen G, Xie L, Tang J, Ben X, Zhang D, et al. Mechanical factors play an important role in pectus excavatum with thoracic scoliosis. J Cardiothoracic Surg. 2012;7:118.

Table 1. Mean Values of the Selected Study Parameters and Median Age in Each Group

	Pectus Index	Asymmetry Index	Flatness Index	Sternal Torsion Angle	Angle of Louis	Median Age (Average rank)*
Ia. Symmetric (n=82)	4.34±0.13	0.98±0.00	1.73±0.02	0.15±0.55	170.28±0.74	5.6 (108.95)
Ib. Asymmetric proper (n=108)	4.72±0.12	1.04±0.01	1.77±0.01	13.06±0.54	166.15±0.46	6.6 (122.18)
Ic. Asymmetric with flat sternum (n=7)	5.19±0.56	1.08±0.02	1.73±0.06	19.44±2.06	179.43±0.43	6.6 (131.79)
IIa. Asymmetric with doubly distorted sternum (n=8)	7.49±0.82	1.06±0.02	1.81±0.05	19.44±2.06	152.05±1.83	10.2 (138.25)
IIb. Asymmetric with severe torsion (n=8)	6.30±1.00	1.09±0.03	1.66±0.04	34.06±1.56	161.73±2.92	6.3 (122.00)
IIc. Reverse asymmetric (n=16)	4.82±0.50	0.95±0.02	1.67±0.04	19.01±1.97	164.08±1.24	4.8 (78.63)
IId Severely depressed (n=1)	41.04	0.85	2.18	0.00	161.00	12.2 (173.00)

*: Kruskal-Wallis test, p=0.175

Table 2. Representative Images of Each Group and Comparison with Other Classification Systems

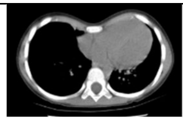
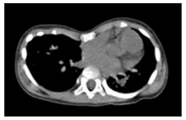
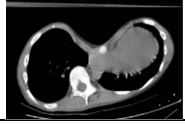
	Horizontal View	Sagital View	Cartoski	Park
Symmetric			Symmetric	Symmetric Asymmetric
Asymmetric proper			Asymmetric Mild sternal torsion	Unbalanced
Asymmetric with flat sternum			Asymmetric Long Length Mild sternal torsion	Unbalanced Broad-flat
Asymmetric with doubly distorted sternum			Asymmetric Localized Mild sternal torsion	Unbalacned Focal
Asymmetric with severe torsion			Asymmetric Severe sternal torsion	Unbalanced
Reverse asymmetric			New type identified by new classification	
Severely depressed				

Table 3. Mutivariate Analysis for Clinical Presentation and Outcome

	Scoliosis (Total N=230)			Parallel Bar (Total N=197)			Bar Rotation (Total N=197)		
	N (%)	HR* (95% CI†)	P	N (%)	HR (95% CI)	P	N (%)	HR (95% CI)	P
Age	-	1.1 (1.0-1.2)	0.059	-	1.2 (1.1-1.3)	<0.001	-	1.1 (1.0-1.2)	0.031
Gender									
Male (vs. female)	11 (5.8)	0.4 (0.1-1.2)	0.206	14(8.5)	1.2 (0.2-8.0)	0.824	9 (5.5)	1.0 (0.2-5.6)	0.979
Connective tissue disease									
Present (vs. none)	3 (42.9)	6.3 (0.8-51.9)	0.074	-	-	-	-	-	-
Classification (vs. Ia)									
Group Ia	4 (4.9)	-	-	2 (2.7)	-	-	2 (2.7)	-	-
Group Ib	7 (6.5)	1.1 (0.3-3.8)	0.695	8 (9.0)	2.5 (0.5-11.2)	0.240	5 (5.5)	1.6 (0.4-7.4)	0.529
Group Ic	0 (0.0)	0.6 (0.0-20.6)	0.825	3 (50.0)	34.9 (3.9-310.1)	0.001	0 (0.0)	2.0 (0.1-57.1)	0.697
Group IIa	4 (50.0)	10.5 (1.7-63.6)	0.008	0 (0.0)	1.1 (0.0-37.6)	0.941	0 (0.0)	1.3 (0.0-35.6)	0.873
Group IIb	0 (0.0)	0.9 (0.0-22.5)	0.870	2 (33.0)	22.7 (2.3-223.6)	0.007	1 (16.7)	7.8 (0.7-81.0)	0.087
Group IIc	1 (6.3)	2.0 (0.3-14.6)	0.312	0 (0.0)	0.6 (0.0-30.4)	0.816	1 (7.7)	3.7 (0.4-33.9)	0.247
Group IId	1 (100.0)	-	-	0 (0.0)	-	-	1 (100.0)	-	-
Pectus Index	-	1.5 (1.2-1.9)	0.002	-	1.0 (0.8-1.3)	0.792	-	1.1 (1.0-1.3)	0.076
Flatness Index	-	1.0 (0.0-53.0)	0.996	-	2.3 (0.0-146.4)	0.699	-	3.6 (0.0-470.8)	0.606
Asymmetry Index	-	0.0 (0.0-8.7)	0.155	-	2.1 (0.0-488555.5)	0.906	-	0.0 (0.0-88.4)	0.304
Sternal Torsion Angle	-	1.0 (1.0-1.1)	0.390	-	1.1 (1.0-1.2)	0.009	-	1.0 (0.9-1.1)	0.580
Angle of Louis	-	1.0 (0.9-1.1)	0.550	-	1.1 (1.0-1.2)	0.017	-	0.9 (0.9-1.0)	0.239

*: Hazard Ratio, †: Confidence Interval

Figure 1. Definitions of selected study parameters. Pectus index = (longest lateral distance of chest wall) / (shortest anteroposterior distance between most depressed point and vertebra); Asymmetry index = (longest anteroposterior distance of left chest wall) / (longest anteroposterior distance of right chest wall); Flatness index = (longest lateral distance of chest wall) / (longer of longest anteroposterior distance of left or right chest wall); STA = angle between sternum and horizontal line, with positive value indicating counterclockwise rotation of sternum and negative value indicating clockwise rotation; and AoL = angle between manubrium and body of sternum on sagittal CT image or simple lateral chest radiograph.

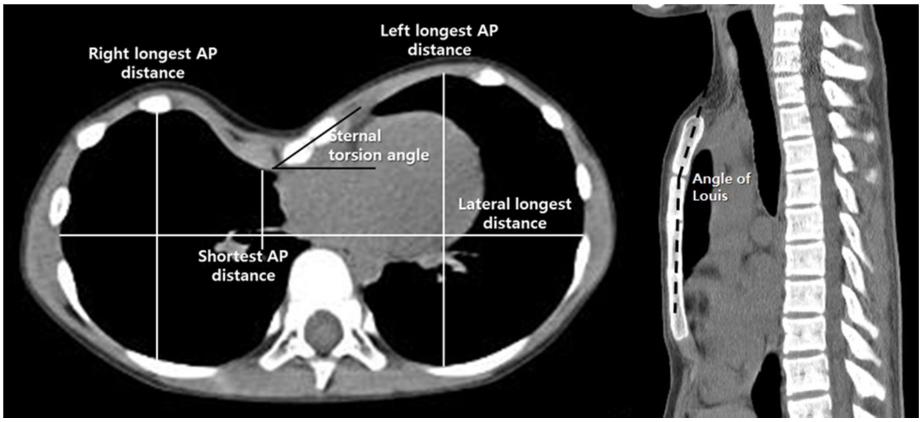
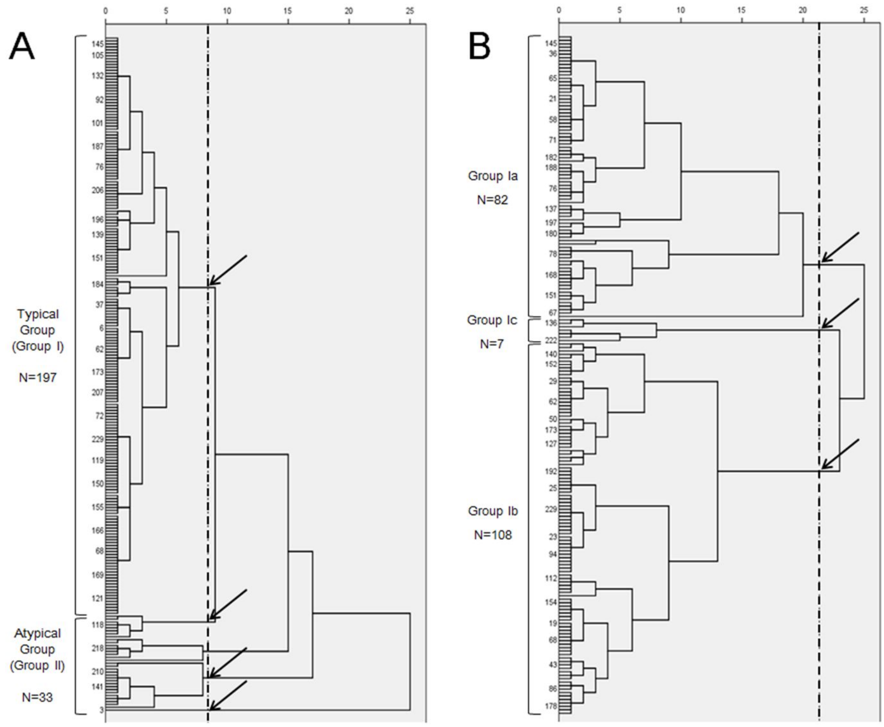


Figure 2. Dendrogram from hierarchical clustering. A. Classification of major groups, typical and atypical. B. Subclassfication of typical major group.



초 록

서론: 기존의 누두흉 분류법들은 주관적인 형태학에 기반한 것들이었다. 연구자들은 객관적인 지표를 기준으로 하는 누두흉의 분류법을 제시하고, 새로운 분류법의 임상적인 의미를 증명하고자 하였다.

방법: 누두흉으로 교정술을 받은 환자 중에 흉부수술의 과거력이 없는 환자들을 대상으로 하였다. 대상 환자들을 흉부 전산화 단층촬영으로부터 얻은 누두흉의 형태학적 지표들을 이용하여 계층적 군집법으로 분류하였다. 형태학적 지표들 간의 상관관계를 분석하고, 분류된 군집별 임상양상의 차이를 분석하였다.

결과: 2001년 1월부터 2013년 8월까지의 기간 중 총 230명의 환자가 연구에 포함되었다. 환자는 정형군 (I군, 197명), 비정형군 (II군, 33명)으로 두 개의 대군집으로 분류되었다. 정형군은 대칭형 아군 (Ia군, 82명), 일반 비대칭형 아군 (Ib군, 108명), 평면흉골 비대칭형 아군 (Ic군, 7명) 등 3개의 아군집으로 하위분류되었다. 비정형군은 이중왜곡흉골 비대칭형 아군 (IIa군, 8명), 중증회전 비대칭형 아군 (IIb군, 8명), 역회전 비대칭형 아군 (IIc군, 16명), 중증 함몰형 아군 (IId군, 1명) 등 4개의 아군집으로 하위분류되었다. 누두흉의 비대칭 지표는 흉골회전각과 양의 상관관계를 보였고 ($P<0.001$, 상관계수

=0.625), 루이스각과는 음의 상관관계를 보였다 (P=0.013, 상관계수 =-0.163). 척추측만증은 대칭형 아군에비하여 이중왜곡흉골 비대칭형 아군에서 더 호발하였다 (P<0.001, 오즈비 10.5, 95% 신뢰구간 1.7-63.6). 너스술식을 시행하였을 때, 대칭형 아군에 비하여 평면흉골 비대칭형 아군 (P=0.001, 오즈비 34.9, 95% 신뢰구간 3.9-310.1)과 중증회전 비대칭형 아군 (P=0.007, 오즈비 22.7, 95% 신뢰구간 2.3-223.6)에서 다중금속판을 사용하는 수술적 술식 변형이 더 많이 적용되었다.

결론: 누두흉의 새로운 분류법으로 정형군, 비정형군 등 2개의 대군집이 분류되었고, 하위분류를 통해서 총 7개의 아군으로 분류되었다. 특정 아군에서 척추측만증의 동반위험이 높고, 너스술식의 다중금속판사용 술식 변형이 더 많이 적용되는 등 분류법에 따른 임상양상 차이를 보였다.