

The correlation between calcaneal valgus angle and asymmetrical thoracic-lumbar rotation angles in patients with adolescent scoliosis

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Abstract. [Purpose] This study aimed to provide a predictable evaluation method for the progression of scoliosis in adolescents based on quick and reliable measurements using the naked eye, such as the calcaneal valgus angle of the foot, which can be performed at public facilities such as schools. [Subjects and Methods] Idiopathic scoliosis patients with a Cobb's angle of 10° or more (96 females, 22 males) were included in this study. To identify relationships between factors, Pearson's product-moment correlation coefficient was computed. The degree of scoliosis was set as a dependent variable to predict thoracic and lumbar scoliosis using ankle angle and physique factors. Height, weight, and left and right calcaneal valgus angles were set as independent variables; thereafter, multiple regression analysis was performed. This study extracted variables at a significance level (α) of 0.05 by applying a stepwise method, and calculated a regression equation. [Results] Negative correlation ($R=-0.266$) was shown between lumbar lordosis and asymmetrical lumbar rotation angles. A correlation ($R=0.281$) was also demonstrated between left calcaneal valgus angles and asymmetrical thoracic rotation angles. [Conclusion] Prediction of scoliosis progress was revealed to be possible through ocular inspection of the calcaneus and Adams forward bending test and the use of a scoliometer.

Key words: Scoliosis, Asymmetrical lumbar rotation angle, Asymmetrical thoracic rotation angle

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INTRODUCTION

Scoliosis is a 3-dimensional vertebral transformation, accompanied by rotation and lateral deviation of each vertebra¹⁾. Scoliosis most often develops in childhood (at around 10 years of age) becoming apparent in adolescence, and is reported to deteriorate rapidly²⁾. An especially fast progression of scoliosis is shown during the adolescent period, when growth is the most active before it is completed, which has worsened in recent years due to a lack of physical activity and due to the prolonged use of smartphones and PCs in awkward postures³⁾.

In cases of scoliosis that escape detection, patients complain of decreased social activity and backache, primarily due to changes in body shape, which are often accompanied by breathing difficulties. In extreme cases, the possibility of death due to a decline in cardiac and pulmonary function

and respiratory failure increases, and surgery is inevitably necessary^{4, 5)}. Thus, early detection is paramount, because the prognosis of undetected scoliosis is poor⁶⁾. The main methods used to diagnose scoliosis at clinical sites are Cobb's angle, Risser sign, vertebral stability and rotation of vertebrae (Perdriolle or Nash-Moe method)⁷⁾. Most of these methods use expensive magnetic resonance imaging (MRI) equipment. In view of the characteristics of scoliosis, patients do not complain of limitations to physical movement or discomfort at early stages, and only receive a diagnosis at clinical sites after vertebral arrangement progression becomes serious. Many studies have found that examination at an early age (11 or 12 years) is appropriate because early screenings for scoliosis enable treatment to be given at a critical point in time⁸⁾.

Although there are many diagnostic methods that use high-priced cutting-edge equipment, active treatment following quick early detection at schools or other youth facilities is the most efficient evaluation method and means of enabling treatment⁹⁾. In addition to examination methods that use harmful radiation, location comparisons of the shoulders, chest, waist, and pelvis by ocular inspection; pulmonary function tests; and measurements using a scoliometer along with forward bending, are also reliable measurement methods¹⁰⁾.

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Table 1. Physical characteristics of subjects

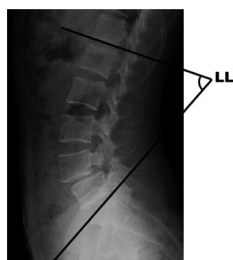
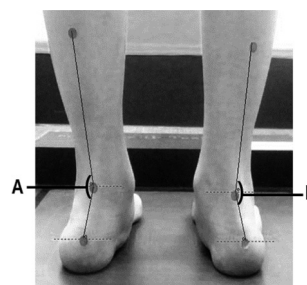
Item class	Age	Height	Weight	BMI
Female (N=96)	15.2±2.4	160.7±5.5	47.9±6.0	18.5±1.9
Male (N=22)	16.5±2.4	174.9±7.3	64.3±10.2	20.9±2.4
Total (N=118)	15.5±2.4	163.4±8.0	50.9±9.5	18.9±2.2

BMI: body mass index

Table 2. The mean and standard deviation of scoliosis related variables

Item class	ATRA	ALRA	LL	LCVA	RCVA
Female (N=96)	7.1±3.4	6.9±4.0	41.6±6.6	7.9±3.8	7.4±3.9
Male (N=22)	6.5±2.9	5.2±3.8	41.6±7.5	6.7±3.7	6.9±4.5
Total (N=118)	7.0±3.3	6.6±4.0	41.6±6.7	7.7±3.8	7.3±4.0

ATRA: asymmetry thoracic rotation angle (°); ALRA: asymmetry lumbar rotation angle (°); LL: lumbar lordosis (°); LCVA: left calcaneal valgus angle (°); RCVA: right calcaneal valgus angle (°)

**Fig. 1.** Total lumbar lordosis (LL) measurement**Fig. 2.** Calcaneal valgus angle measurement (A: left calcaneal valgus angle [°], B: right calcaneal valgus angle [°])

This study carried out a correlation analysis based on quick predictive methods with the naked eye, such as the calcaneal valgus angle, the calcaneal angle and Adam's forward bending test, in front-line facilities such as schools, then checked those methods' preciseness and reliability in order to present the most effective evaluation method. The purpose of this study was to detect adolescent scoliosis early, to prevent unnecessary surgeries and aid proper treatment.

SUBJECTS AND METHODS

This study targeted adolescents who received diagnoses of idiopathic scoliosis with 10° or more of Cobb's angle on whole spine AP X-ray examination from rehabilitation medicine specialists. After potential subjects were informed of the objectives and procedures of the experiment, those who understood the purpose of the study, and agreed to actively participate in the work were enrolled in the study. This study received approval from the Institutional Review Board (IRB) of Clinical Test at Gwangju Oriental Hospital of Dongshin University on September 9, 2013 (IRB NO: DSGOH-017). This study selected those subjects who had no experience with conservative treatment for scoliosis in the past, those who had no other problems in terms of orthopedics, and those with no history of cardiac problems and/or pulmonary disease. The participants' physical properties are

shown in Table 1.

For the Adam's forward-bending test, participants placed their feet together, allowing their arms to hang naturally, and bent their upper bodies forward 90° from the standing position. Examiners used visual evaluations, with their eyes at levels equal to those of the participants' backs, and measured asymmetrical thoracic rotation angles (ATRA) and asymmetrical lumbar rotation angles (ALRA) at the rib hump and lumbar hump using a scoliometer (USA) (Table 2)¹¹.

Participants were instructed to stand straight in order to view lumbar lordosis angles from the sagittal plane, bending the upper limbs forward by 90°, and keeping the eyes forward. Side radiographs were taken at 1.5 m distance from the cassette. Lumbar lordosis angles were used to calculate crossed angles by drawing each line on the upper end-plate of the first lumbar vertebra and the upper end-plate of the first sacral vertebra, giving the calculated angle of the size of the curvature as shown in Fig. 1¹².

For the analysis of the calcaneal valgus angles, this study performed a plumb line test¹³, as shown in Fig. 2, using the Body Balance Index System, STEPS®, Korea. This study measured the angle between the mid-calcaneal axis and the mid-talar axis.

This study computed the mean and standard deviation

Table 3. Summary of stepwise regression procedure for dependent variable ATRA

Step	Partial R2	Model R2	C(p)
BMI***	0.13	0.13	4.48
LCVA*	0.04	0.17	1.32

BMI: body mass index; LCVA: left calcaneal valgus angle (°); ***p<0.0001 (F=16.11), *p<0.05 (F=5.24)

Table 5. Summary of stepwise regression procedure for dependent variable ALRA

Step	Partial R2	Model R2	C(p)
LL**	0.07	0.07	1.46
BMI	0.02	0.09	1.35

BMI: body mass index; LL: lumbar lordosis (°), **p<0.001 (F=7.47)

of the factors related with scoliosis, and extracted variables with correlation at significance level α of 0.05. This set the degree of scoliosis as a dependent variable to predict thoracic and lumbar scoliosis using ankle angles and physique factors, and set height, weight, and left and right calcaneal valgus angles as independent variables, and then performed a multiple regression analysis to find meaningful explanatory variables. Variables were extracted at a significance level (α) of 0.05 by applying a stepwise method, and then the regression equation was calculated.

RESULTS

Tables 3 and 4 show the results of variable extraction and regression equations using a stepwise method of multiple regression analysis in order to predict thoracic scoliosis through height, weight, BMI, and left and right calcaneal valgus angles.

As shown in Table 3, the variables that could predict only thoracic scoliosis were selected by applying the stepwise method; thereby, BMI and left calcaneal valgus angles were selected. BMI and left calcaneal valgus angles explained 17% of ATRA, and were statistically significant variables (p<0.05).

To estimate ATRA as shown in Table 4, this study set BMI and left calcaneal valgus angles as independent variables, and thoracic scoliosis angles as dependent variables, and constructed a regression equation. The root mean square error (RMSE) was 1.48°; therefore, BMI and left calcaneal valgus angles were effective variables to predict thoracic scoliosis (p<0.05).

Tables 5 and 6 show the results of extraction of variables and the regression equation using stepwise multiple regression analysis methods in order to predict the degree of lumbar scoliosis through height, weight, BMI and left and right ankle valgus angles.

As shown in Table 5, as the result of extracting the variables that can predict lumbar scoliosis by applying stepwise multiple regression analysis, lumbar lordosis and BMI were selected. The two variables explained 9% of ALRA, and

Table 4. Multiple regression analysis for predicting ATRA

Variable	Parameter estimate	Standard error	Type II SS
Intercept***	14.19	2.72	245.88
BMI**	-0.45	0.13	106.79
LCVA*	0.18	0.08	47.51

$$\text{ATRA} = 14.19 - 0.45228 \times \text{BMI} + 0.17 \times \text{LCVA}$$

BMI: body mass index; ATRA: asymmetry thoracic rotation angle (°); LCVA: left calcaneal valgus angle (°); ***p<0.0001 (F=27.13), **p<0.001 (F=11.78), *p<0.05 (F=5.24)

Table 6. Multiple regression analysis for predicting ALRA

Variable	Parameter estimate	Standard error	Type II SS
Intercept***	17.23	3.72	324.68
BMI	-0.27	0.18	32.49
LL*	-0.13	0.06	76.61

$$\text{ALRA} = 17.23 - 0.2696 \times \text{BMI} - 0.13 \times \text{LL}$$

BMI: body mass index; ALRA: asymmetry lumbar rotation angle (°); LL: lumbar lordosis (°), ***p<0.0001 (F=21.48), *p<0.05 (F=5.07)

were statistically significant variables (p<0.05).

BMI and lumbar lordosis were as independent variables, and ALRA was set as a dependent variable to estimate ALRA, formulating the regression equation shown in Table 6. The RMSE of estimation was 1.68°, therefore, the y-intercept was not zero (p<0.0001), and lumbar lordosis was an effective variable for predicting lumbar scoliosis (p<0.05).

DISCUSSION

This study sought to identify degrees of scoliosis through the left and right calcaneal valgus angles, which can be observed with the naked eye without radiation techniques, and by using a scoliometer, with which measurements can easily be conducted. To enhance the reliability of this study, correlations were analyzed with each variable by additionally associating lumbar lordosis in the sagittal plane.

Ultimately, a negative correlation between lumbar lordosis (LL) and ALRA was revealed (R=-0.266). Compensation for this can be revealed through observing the degree of asymmetry in the tuberosity of the calcaneus. This is consistent with other studies¹⁴⁾ which found that imbalances are revealed in the sagittal plane. Compensation can be divided into two, namely, intraspinal compensation and extraspinal compensation. Intraspinal compensation is further divided into thoracic compensation and pelvic compensation. Due to intraspinal compensation, muscle function changes occur, resulting in hip, lumbar and cervical pain, while proper standing positions cannot be maintained^{15, 16)}.

The greatest degree of LL is found at the third lumbar vertebra, fourth lumbar vertebra, or at the disk between them. Lumbar segment lordosis starts between the first and second lumbar vertebrae, and gradually increases in the lower section. It was found that the greatest degree of seg-

ment lordosis is found between the fourth and fifth lumbar vertebrae, and the angle between the fifth and first lumbar vertebrae accounts for 60% of total lordosis¹²). The pelvic tilt is the angle made by the line connecting the center of the sacral vertebral superior endplate and hip axis with the central plumb line, and is a location indicator reflecting pelvic compensation mechanisms when there are sagittal plane imbalances¹⁷). From recent studies, it was revealed that the shape of the pelvis is important in determining the curve of the sagittal plane¹⁷⁻¹⁹).

Vialle et al.¹⁹) revealed that some correlation exists between pelvic incidence angles and LL in normal individuals. This assertion nearly matched the findings of this study, in that significant correlation exists between lumbar lordosis angles and ALRA.

This study revealed that the left calcaneal valgus angle has a correlation with ATRA ($R=0.282$).

When the left ankle arch collapses causing flat feet, and both shoulders become imbalanced, scoliosis appears to develop. Namely, imbalance from the feet affects the legs, pelvis and vertebrae; therefore, scoliosis is believed to be resultant. According to a preceding study, when load is added to a specific lower limb, energy consumption increases. This energy consumption increase was reported to increase more when it was added to the end of the lower limb, rather than close to the trunk, despite the same weight²⁰). Scoliosis is a disease in which 3-dimensional transformation of the vertebrae bend together to one side with vertebral rotation of one foot's load, arising from an imbalance of the feet; therefore, it was reported that a change of the angle supporting the body weight, including shoes, can affect the prognosis of the disease²¹). Postural asymmetries are also associated with the risk of progression in idiopathic scoliosis. Scoliotic curves are commonly seen with right and left anatomical leg length differences²²). The pelvic obliquity attributable to rotational malalignment results in compensatory curves of the spine or the accentuation of any pre-existing curves. Carole et al.²³), tested the reliability of a quantitative clinical posture assessment tool among persons with idiopathic scoliosis. The dependability coefficients (ϕ) for posture indices are presented in the tibio-calcaneal angles (L and R; $\phi=0.51$ and 0.53 , respectively). This means that checking feet stability is important when examining scoliosis²⁴). According to 3-dimensional analysis results, it was reported that functional shoes are helpful to vertebrae, especially for lumbar muscular strength consolidation and vertebral health, through the improvement of feet stability²⁵).

Based on the results of this study and the many preceding studies, the progress of scoliosis can be predicted to some degree, depending on visual checks of the sole arch shape, tuberosity of the calcaneus, Adam's forward bending test, and the use of a scoliometer. Idiopathic scoliosis develops during adolescence and progresses rapidly²⁶), and therefore correction becomes difficult if the treatment window passes. Therefore, it is important to diagnose scoliosis early²⁷). If scoliosis is diagnosed in its early stages through prompt examination and evaluation at schools or other facilities, curvature progression and unnecessary surgeries can be prevented through conservative treatment with walking aids and/or exercise, when curvatures are slight²⁸).

This study had some limitations. First, calcaneal valgus angles and asymmetrical thoracic-lumbar rotation angles were only assessed in patients with adolescent scoliosis; there was no control group. Moreover, direct analysis of the correlations between Cobb angles and calcaneal valgus angles and asymmetrical thoracic-lumbar rotation angles was not performed. Therefore, it is unlikely that the study's results can be generalized. Future studies will be required to classify major curvatures in detail, and to analyze the relationship between Cobb angles, asymmetrical thoracic-lumbar rotation angles and calcaneal valgus angles, the results of which may contribute to streamlined predictions and evaluations of idiopathic scoliosis.

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