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Comparative study of the occurrence of vertebral scoliosis and spinal deviation parameters in patients with or without facial asymmetry

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-Abstract-

Comparative study of the occurrence of vertebral scoliosis and spinal deviation parameters in patients with or without facial asymmetry

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Background and Purpose: Facial asymmetry (FA) is one of the most common maxillofacial deformities, and vertebral scoliosis (VS) is a systemic change of vertebrae. The aim of this study was to evaluate VS in whole-spine standing anteroposterior radiographs in patients with and without FA; to use CT, posterior-anterior (P-A) cephalogram, and clinical facial photography to evaluate the degree of FA; and to investigate the relationship between parameters for FA and those for VS.

Patients and Methods: In 171 patients, FA was evaluated with CT, P-A cephalogram and clinical facial photography, the menton deviation from the vertical line more than 3° was classified to FA group, and less than 1.5° to non-FA group. Patients in whom the menton deviation was between 1.5 and 3 degrees were considered the intermediate group, and their data were excluded in the comparison between FA and non-FA groups. Three parameters for VS (∠Cobb, ∠Shoulder, ∠Trunk) in whole-spine standing anteroposterior radiography and eight parameters for FA (∠Me^{cep}, ∠NaMe, ∠Yaw, ∠NaANS, ΔFRa, ΔPRa, ΔMe-Go, ΔCd-Go) in CT, P-A cephalogram and clinical facial photography were measured and statistically evaluated.

Results: In P-A cephalogram evaluation, there were 43 patients with FA and 76 patients without FA. In asymmetry group, there were 9 VS patients (20.9%) and the mean Cobb`s was 7.52 ± 3.74°. In non-asymmetry group, there were 8 VS patients (10.5%) and the mean Cobb`s was 7.09 ± 2.89°. But the differences in number of VS patients and the mean Cobb`s angle between FA group and non-FA group were not statistically significant. In CT evaluation, 57 patients showed FA and 71 patients did not have FA. In FA group, there were 14 VS patients (24.6%), and the mean Cobb`s angle was 7.41 ± 3.6°. In non-FA group, there were 8 VS patients (11.1%), and the mean Cobb`s angle was 6.62 ± 2.8°. The differences in terms of the number of VS patients and the mean Cobb`s angle between two groups were statistically significant (P = 0.04 and 0.03, respectively). Cobb`s angle has statistically significant correlation with ∠NaMe ($R$ = 0.169, $P$ = 0.02). The direction of FA has statistically significant agreement with the direction of shoulder balance, which were opposite ($P$ = 0.03, κ = -0.165). In particular, when the direction of Cobb`s angle, shoulder balance and trunk balance were in identical, the direction of FA and the direction of VS were in higher agreement in the opposite directions (*P* = 0.02, κ = -0.338)

Conclusion: With regard both to number of patients with VS and to Cobb's angle, only multi-slice CT scans showed a statistically significant difference between patients with FA and those without FA. Cobb's angle was correlated with menton deviation on multi-slice CT scans, and the direction of FA was opposite that of VS. Our findings suggest that the evaluation of VS is needed in the analysis of and treatment planning for FA in patients who have both FA and VS.

KEYWORDS: Facial asymmetry, Scoliosis, Shoulder balance, Coronal trunk balance, Correlation

Contents

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1. Introduction

When the human body develops with bilateral external symmetry, the right and left sides of the external human body can be divided into mirror images. Because of biological variables, as well as environmental disturbances, bilateral symmetry is rarely perfect.[1] Many faces have a mild degree of asymmetry; in fact, slight asymmetry is often unperceived by its carriers and everyone around them. However, a severe degree of asymmetry is typically noticeable, which can negatively affect an affected person's facial esthetics.[1, 2] Clinical studies of facial asymmetry (FA) have revealed a prevalence ranging from 12% to 37% in the United States,[3-5] 23% in Belgium,[6] and 21% in Hong Kong.[7] Radiographic examinations have shown that the prevalence of FA is higher than 50%.[8, 9] FA occurs in patients with disharmony of jaw growth, especially in the musculoskeletal development of the head and neck area.[10] Certain congenital problems, such as neurofibromatosis and hemifacial microsomia, may affect FA, but the exact pathogenesis of acquired FA is still unknown.[2] Major contributing factors in the literature are overgrowth or undergrowth of the mandibular condyle, pressure during birth, trauma to the head and neck area, dysplasia of the mandibular condyle, and occlusal interference.[1, 2] Patients with FA may alter head posture to compensate for the FA by tilting the head position at an angle opposite the asymmetrical side.[10]

The term of vertebral scoliosis (VS) was derived from the ancient Greek word “skolios” (curved, crooked) and was first established by Galen (130–201 AD).[11] VS is the condition in which one or more vertebrae are tilted or rotated and deviate to one side. The measurement of Cobb’s angle—the angle between the highest and lowest tilted vertebrae—is a routine way to evaluate VS.[11] If the angle between the superior endplate of the highest vertebra and inferior end plate of the lowest vertebra is more than 10 degrees, the condition is defined as VS.[11, 12] Bunnel defined idiopathic VS as a systemic change of vertebrae with a change in Cobb’s angle by 10 degrees or more.[13] An estimated 65% of scoliosis cases are idiopathic, approximately 15% are congenital, and approximately 10% are secondary to a neuromuscular disease.[14] Idiopathic scoliosis is defined as VS without definite causes (such as tumor, inflammation, neural disease, muscular disease, disorders of central nervous system, and disorders of vertebrae).[11, 13, 15]

Of the many hypotheses concerning the cause of idiopathic VS, none has yet been clearly proven. It is believed that multifactorial causes such as genetic factors, biochemical growth, nerve factors, and muscular factors combine in a complex manner to produce VS.[11] It is reported that the degree of VS is influenced by deformities of the musculoskeletal system.[16, 17] Unstable posture, imbalance of shoulders, and malocclusions can be among the factors contributing to idiopathic VS.[17-19] Similarly, it has been speculated that FA is related to VS because, as mentioned, many patients with FA alter head position, which may change body posture.[17, 20, 21]

Only a few studies of the relationship between VS and FA have been based on this speculation.[20-23] In some studies, posterior-anterior (P-A) cephalogram was used to evaluate whether VS had a positive relationship with FA,[21,23] and the results were contradictory: There were significant differences and correlations in some studies[20, 21, 23] but not in other studies.[20, 22] However, P-A cephalogram is characterized by image distortion and difficulty in finding exact landmarks, especially the menton.[24] Moreover, ear rods are used to stabilize head posture during P-A cephalogram, and the locations of the external auditory meatus on the right and left sides are variable not only in the height but also in the anterior-posterior position.[25, 26] The differences in vertical location of the external auditory meatus on the right and left sides with changes in head positioning does not affect FA evaluation because a horizontal reference line can extend between the latero-orbitale points on both sides, and a vertical reference line, perpendicular to the horizontal reference line, passes through the crista galli without image distortion.[27, 28] However, the yawing changes in head posture, as evidenced by different anterior-posterior positions of the external auditory meatus, can lead to distortion in the P-A cephalogram, which results in positional changes of landmarks and reference lines.[27, 28] On the other hand, landmarks and reference lines can be reproduced without great errors, and three-dimensional (3D) measurement on computed tomographic (CT) scans are exact.[24]

The aim of this study was to evaluate VS in whole-spine standing anteroposterior radiographs in patients with and without FA; to use CT, P-A cephalogram, and clinical facial photography to evaluate the degree of FA; and to investigate the relationship between parameters for FA and those for VS.

2. Patients and Methods

2.1. Patients

This study was approved by the Institutional Review Board of Seoul National University Dental Hospital. The study was conducted with 171 patients who underwent orthognathic surgery at Seoul National University Dental Hospital for dentoskeletal problems between November 2014 and September 2016. Preoperative 3D multi-slice CT, whole-spine standing anteroposterior radiography, and P-A cephalogram were performed in all patients. In 30 randomly selected patients, preoperative clinical facial photographs were also taken. Patients' mean age was 25.8 ± 5.9 years (range, 18.1–33.6 years), and the male-to-female ratio was 11:9.

2.2. Methods

2.2.1. Evaluation of FA

FA was evaluated in P-A cephalogram, multi-slice CT scans, and clinical facial photographs.

2.2.1.1. P-A cephalogram

On P-A cephalometric radiograph, a line representing the horizontal reference line (H-line) was drawn between the latero-orbitale points, where greater wing of sphenoid bone and lateral orbital rim meet, and a line representing the vertical reference line (V-line) was drawn perpendicular to the H-line, passing through the crista galli. A line drawn between the midpoint of the H-line and the menton served as the vertical midpoint reference line (V-midline). The deviation between the V-midline and the V-line on P-A cephalometric radiographs was defined as $\angle Me^{Cep}$. Patients were considered to have FA if $\angle Me^{Cep}$ was more than 3 degrees (FA group), and those in whom $\angle Me^{Cep}$ was less than 1.5 degrees were considered not to have FA (non-FA group; Figure 1A). Patients in whom $\angle Me^{Cep}$ was between 1.5 and 3 degrees were considered the intermediate group, and their data were excluded in the comparisons between FA and non-FA groups.

2.2.1.2. Clinical facial photography

In clinical facial photographs, the interpupillary line served as the H-line, and the line perpendicular to the H-line served as the V-line. The line between the center of the soft tissue nasion and the menton served as the V-midline. The deviation between V-midline and V-line on P-A cephalometric radiographs was defined as $\angle Me^{Pho}$. Patients were considered to have FA if $\angle Me^{Pho}$ was more than 3 degrees, and those in whom $\angle Me^{Pho}$ was less than 1.5 degrees were considered not to have FA (Figure 1B). Patients in whom $\angle Me^{Pho}$ was between 1.5 and 3 degrees were considered the intermediate group, and their data were excluded in the comparison between FA and non-FA groups.

2.2.1.3.Multi-slice CT

In all patients, a multi-slice CT scanner (SOMATOM® sensation 10; Siemens Co., Munich, Bayern, Germany) was used to obtain 3D multi-slice CT scans of the face, with the following parameters: 120 kVp, 80 mAs, and a slice thickness of 0.75 mm. Digital image files were saved in a Digital Imaging and Communications in Medicine format and imported into 3D Slicer® 4.1 imaging software (Harvard Medical School, Boston, MA, USA). CT images were rendered as volumetric images. The reconstructed sagittal, axial, and coronal slices and 3D images were then obtained.

Three reference planes were constructed: (1) the Frankfort horizontal plane, which connected the right and left orbitales and the midpoint of both porions; (2) the midsagittal reference plane, which was perpendicular to the Frankfort horizontal plane and passed through the nasion; and (3) the coronal plane, which was perpendicular to both the Frankfort horizontal and midsagittal planes and passed through the midpoint of both planes. After landmarks and reference lines were determined (Figure 2), seven angular and linear parameters were measured, described as follows:

(1) Na-Me inclination (∠NaMe; in degrees): the angle between the midsagittal plane and the line connecting the nasion and the menton

(2) Na-ANS inclination (∠NaANS; in degrees): the angle between the midsagittal plane and the line connecting the nasion and anterior nasal spine

(3) Posterior ramal angle (∠PRA; in degrees) on the right and left sides: the angle between the coronal plane and the line connecting the posterior condylion (Cd^P) and the posterior gonion (Go^P) on the right and left sides.

(4) Frontal ramus angle (∠FRA; in degrees) on the right and left side: The angle between the midsagittal plane and the line connecting the lateral condylion (Cd^L) and the lateral gonion (Go^L) on the right and left sides.

(5) Ramus length (Cd-Go; in millimeters) on the right and left side: The distance between the Cd^L and Go^L on the right and left sides.

(6) Mandible yawing (∠Yaw; in degrees): The angle between the midsagittal plane and the line connecting the menton and the midpoint of both Go^Ls.

(7) Body length (Me-Go; in millimeters) on the right and left sides: The distance between the menton and the Go^L on the right and left sides.

The differences between right and left values of the ∠FRA, ∠PRA, Cd-Go, and Me-Go were defined as ΔFRA, ΔPRA, ΔCd-Go, and ΔMe-Go (Table 1 and 2; Figure 3).

Patients considered to have FA if the ∠NaMe was more than 3 degrees, and those in whom ∠NaMe was less than 1.5 degrees were considered not to have FA.

2.2.2. Evaluation of VS in whole-spine standing anteroposterior radiography

2.2.2.1. Cobb's angle

The measurement of Cobb's angle (∠Cobb) in whole-spine standing anteroposterior radiography is known as the "gold standard" for evaluating VS. Cobb's angle is the angle between the line parallel to the superior vertebral end plate of the most tilted vertebra at the top of the spinal curve and the line parallel to the inferior vertebral end plate of the most tilted vertebra at the bottom to the spinal curve. If the Cobb's angle is larger than 10 degrees, the affected patient is considered to have VS (Figure 4A).

2.2.2.2.Coronal trunk balance

With a measurement of coronal trunk balance (∠Trunk), we evaluated whether the upper spine was in a normal location or off to one side. It was defined as the angle between the center sacral line (the line crossing the center of the sacrum) and the C7-S1 line (the line between midpoint of C7 and the spinous process of S1; Figure 4B).

2.2.2.3.Shoulder balance

Lack of shoulder balance (∠Shoulder) is one of notable aspects of clinical deformity caused by scoliosis. For the measurement of shoulder balance, the V-line served as the line of gravity, and the H-line served as the line perpendicular to the gravity line. The point of shoulder peak was the most superior point of the clavicle. Shoulder balance was defined as the angle between the H-line and the line connecting both shoulder peaks (Figure 4C).

2.2.3. Methodical errors

We estimated variable errors in parameter measurements by re-measuring parameters on the P-A cephalogram, clinical facial photographs, and multi-slice CT scans of 20 randomly selected patients. Differences in parameters were determined by double measurements of reference points and selected landmarks. The methodical errors were calculated by a common formula for middle square error ($S^2 = \Sigma d^2/2n$, where d is the difference, in degrees or millimeters, between first and second measurements and n is the number of double measurements). The maximum error was 0.98 degrees in angle and 0.73 mm in distance (Table 3).

2.3. Statistical analysis

We used SPSS® 9.0 (IBM Co., Armonk, NY, USA) to statistically analyze our measurements. We performed independent *t* tests and χ^2 tests to determine any significant differences. Pearson correlation analysis was used to determine correlation between measured parameters for FA and for VS. A *P* value of less than 0.05 was considered statistically significant.

3. Results

3.1. Comparisons of image tools for FA evaluation

To select an adequate method of evaluating FA among parameters in the three imaging tools (P-A cephalogram, multi-slice CT, and clinical facial photography), we evaluated FA and VS in 30 randomly selected patients. These patients were divided into the FA group and non-FA group, and, using independent *t* tests for the three imaging tools, we evaluated differences in measured parameters between the two groups. We also investigated the correlation among the parameters by using the Pearson correlation test.

The parameters involving menton deviation showed statistically significant differences in each of the three imaging tools. P-A cephalogram demonstrated statistically significant differences in five parameters (∠NaMe, ∠Me^{Pho}, ∠Yaw, and ΔFRA), whereas multi-slice CT scans demonstrated statistically significant differences in eight parameters (∠Me^{Cep}, ∠Me^{Pho}, ∠Yaw, ∠NaANS, ΔFRA, ΔPRA, ΔMe-Go, and Cobb's angle). However, clinical facial photographs demonstrated no statistically significant difference in any parameter for VS and FA (Table 4).

The Pearson correlation test produced similar results. The parameters involving menton deviation (∠NaMe, ∠Me^{Cep}, and ∠Me^{Pho}) were mutually correlated. CT scans demonstrated correlations among three parameters (∠Yaw, ∠NaANS, and ΔMe-Go), and P-A cephalogram also demonstrated correlations among five parameters (Cobb's angle, ∠Yaw, ∠NaANS, ΔFRA, and Cobb's angle) (Table 5).

Because of the results, clinical facial photographs were excluded from further evaluations, and measurements of ∠Me^{Cep} on P-A cephalogram and ∠NaMe on multi-slice CT scans were chosen to evaluate FA.

3.2. Evaluation of VS and spinal deviation

Of the 171 patients, 30 (17.54%) had VS. In these patients, the mean Cobb's angle, shoulder balance angle, and trunk balance angle were 13.16 ± 3.44 degrees, 1.95 ± 1.31 degrees, and 1.06 ± 0.72 degrees, respectively; in patients without VS, these mean angles were 6.19 ± 2.05 degrees, 1.54 ± 1.09 degrees, and 0.79 ± 0.61 degrees, respectively. The differences in Cobb's angle between patients with and without VS were statistically significant (Table 6). Among patients with VS, a greater number had FA and increased degrees of menton deviation in comparison with patients without VS. However, differences in menton deviation (∠NaMe) were statistically significant only on multi-slice CT scans (Table 7).

3.3. CT evaluation of spinal deviation in patients with FA

According to multi-slice CT evaluation, 57 patients had FA and 71 did not. Of those with FA, 14 had VS, and the mean Cobb's angle in these patients was 8.01 ± 4.37 degrees. Of the patients without FA, 8 had VS, and the mean Cobb's angle in those patients was 6.62 ± 2.79 degrees. The difference in numbers of patients with VS between the FA and non-FA groups was statistically significant, according to a χ^2 test ($P = 0.04$). Independent t tests also showed significant differences in mean Cobb's angles ($P = 0.03$). Of eight parameters for FA ($\angle Me^{Cep}$, ∠NaMe, ∠Yaw, ∠Na-ANS, ΔFRA, ΔPRA, ΔMe-Go, ΔCd-Go), all except ΔPRA were significantly different between the two groups (Tables 8 and 9; Figure 5A).

3.4. P-A cephalographic evaluation of spinal deviation in patients with FA

P-A cephalographic evaluation revealed 43 patients with FA and 76 patients without FA. Of those with FA, 9 had VS, and the mean Cobb's angle in these patients was 7.52 ± 3.74 degrees. Of patients without FA, 8 had VS, and the mean Cobb's angle in those patients was 7.09 ± 2.89 degrees. However, the differences in number of patients with VS and in the mean Cobb's angle between the FA and non-FA groups were not statistically significant. The differences in six parameters for FA (∠Me^{Cep}, ∠NaMe, ∠Yaw, ΔFRA, ΔPRA, and ΔCd-Go) between the two groups were statistically significant (Tables 10 and 11; Figure 5B).

3.5. Correlation between FA and spinal deviation

Pearson correlation analysis was performed for three parameters of spinal deviation (Cobb's angle, shoulder balance, and coronal trunk balance) and eight parameters of FA (∠Me^{Cep}, ∠NaMe, ∠Yaw, ∠Na-ANS, ΔFRA, ΔPRA, ΔMe-Go, and ΔCd-Go). Cobb's angle was significantly correlated with ∠NaMe (P = 0.02, R = 0.169; Figure 6). Menton deviation observed on P-A cephalogram (∠Me^{Cep}) was not significantly correlated with parameters for spinal deviation (Table 12).

On P-A cephalogram, menton deviation (∠Me^{cep}) was correlated with five parameters for FA (∠NaMe, ∠Yaw, ΔFRA, ΔPRA, and ΔCd-Go) but not with two (∠Na-ANS and ΔMe-Go). On multi-slice CT scans, menton deviation was correlated with six parameters for FA (∠Me^{cep}, ∠Na-ANS, ∠Yaw, ΔFRa, ΔMe-Go, and ΔCd-Go) but not one (ΔPRA). Pearson correlation coefficients for parameters for FA were higher for multi-slice CT scans than for P-A cephalogram (Table 12).

3.6. Direction of FA and scoliosis

The direction of FA was correlated with Cobb's angle, shoulder balance, and trunk balance in many cases (Table 13). There was statistically significant agreement between the direction of FA and the direction of shoulder balance, which were opposite according to χ^2 tests (P = 0.03, κ = −0.165). In particular, when the direction of Cobb's angle, shoulder balance, and trunk balance were identical (52 patients), the direction of FA and the direction of VS were in higher agreement in the opposite directions (P = 0.02, κ = −0.338; Table 14; Figure 7).

4. Discussion

The human face is often mildly asymmetrical, but slight asymmetry is usually not perceived in daily life by other people.[2, 8, 29-31] When the degree of asymmetry is severe, it can not only negatively affect facial esthetics[30, 32, 33] but also can cause other functional problems, such as occlusal disturbance and temporomandibular joint disorders.[34, 35] Mandibular deviation has been reported to be strongly related to condylar path[36] and to muscle activity through various neurophysiological and anatomical mechanisms.[37]

P-A cephalogram and clinical facial photographs have been used frequently to evaluate FA,[1] but the reliability of P-A cephalogram is limited because of overlapping anatomical structures, magnification errors, and image distortion.[24] Clinical facial photography also has disadvantages for FA evaluation because head position varies in normal clinical facial photography and skeletal FA can be obscured by overlying soft tissue.[38-40] CT scans have been used widely used for 3D measurements[39-41] and can greatly reduce the problems of the other imaging methods, and it enables more accurate analysis of FA.[42-44] In this study, P-A cephalogram, clinical facial photographs, and multi-slice CT scans were evaluated adequacy in the analysis of FA by the measurement of menton deviation and six parameters related to FA. Our results showed that multi-slice CT and P-A cephalogram were appropriate imaging tools for evaluating FA, whereas clinical facial photography demonstrated no correlation among these parameters.

In the studies about the prevalence of FA, Sheats et al.[4] reported that in terms of mandibular midline deviation from the maxillary midline, the prevalence of FA was approximately 12%. Severt and Proffit[3] reported that 34% of individuals were found to have FA; deviation of the chin was the most noticeable feature of asymmetry. In our study, the frequency of FA was demonstrated to be 36.4% by CT scans and 29.3% by P-A cephalogram. These rates a little higher than those reported in the literature, and they may include patients with severe malocclusion that was corrected by orthognathic surgery in our study.

Abnormal head position can affect the mandible position, which can then affect the posture of the neck and trunk.[45] Tilting of the occlusal plane, the mandibular plane, and the Frankfort plane had a significant relationship to the tilting of the cervical vertebra.[46] Huggare et al. showed that abnormal structure of the cervical vertebrae was closely related to mandibular deviation.[47] Kondo et al. reported that preoperative functional assessments of jaw muscles and neck muscles are essential in the treatment of patients with skeletal mandibular deviation, and that body posture is related to the balance of muscles.[48]

Adolescent idiopathic VS is a 3D deformation of the spine without clear etiology. Because there is no clear causal factor, its development is generally believed to be multifactorial. Genetics plays an important role, but muscular imbalance, deviation from the standard growth pattern, neuromuscular or conjunctive tissue alterations, and other environmental factors have been also suggested as possible causal factors.[14, 18, 49-51] Idiopathic VS can cause skeletal problems such as shoulder imbalance, trunk asymmetry, and leg-length discrepancy.[49, 50, 52, 53] Other musculoskeletal anomalies such as lower and upper limb deformities and hip dysplasia also can occur in association with VS. In the facial region, the rotation of orbital, maxillary, and mandibular plane, as well as lateral malocclusion, were observed in patients with VS in one study.[20] Lippold et al. found that idiopathic VS was correlated with malocclusion.[18]

The prevalence of adolescent idiopathic VS ranges from 1.66% to 6.17%, with differences in race and age.[12] In our study, the prevalence of VS was 17.54% (30 of 171 patients) which was about three times higher than the reported prevalence. Our finding may be attributable to patients' skeletal malocclusion and FA. On multi-slice CT evaluation, VS was observed in 24.56% of patients with FA (14 of 57 patients), which was significantly different from the prevalence of VS of 11.11% (8 of 71 patients) in non-FA group, which was, however, approximately twice as high as the normal prevalence. Skeletal malocclusion in the non-FA group, which was corrected by orthognathic surgery, would account for this rate. In a study of patients with scoliosis and dental occlusion, Saccucci et al. reported a higher prevalence of scoliosis among the patients with malocclusion.[17]

In a few studies, researchers have reported the relationship between adolescent idiopathic VS and FA, but the results have been equivocal. Some studies showed that there was no statistically significant difference among patients with VS with regard to FA.[20, 22] On the other hand, Hong et al. showed a statistically significant correlation between Cobb's angle and menton deviation visible on P-A cephalogram[20] in patients with VS, and Zhou et at. showed that the degree of mandibular deviation visible on P-A cephalogram was correlated with the degree of VS and trunk imbalance.[21] These investigators used P-A cephalogram to evaluate FA, even though FA is a 3D deviation of the mandible and maxilla; thus we expected 3D CT evaluation to be a more precise approach in evaluating FA. In terms of Cobb's angle and the degree of menton deviation, we found no significant difference between the two on P-A cephalogram, but we did find a significant difference on multi-slice CT scans. We also found no significant differences on P-A cephalogram between the FA and non-FA group with regard to the number of patients with VS and Cobb's angle, whereas on multi-slice CT scans, they were significantly different.

A relationship between VS and shoulder balance and trunk balance has been reported.[54-56] Shoulder balance plays an important role in the appearance of patients with VS.[53, 54, 56] Our finding on multi-slice CT scans of statistically significant differences in Cobb's angle and trunk balance between patients with VS group and those without VS group are consistent with those reports.

The association between the directions of FA and VS have been studied, but the outcomes have been equivocal. Zhou et at. showed that the direction of FA was opposite to the direction of lateral bending of cervical vertebrae and suggested that mandibular deviation had an adverse effect on the shape of the spine and trunk balance in the coronal plane.[21] However, Laskowska et al. did not find any relevant relationship between the directions of scoliosis and FA.[23] In our study, the direction of VS was opposite to the direction of shoulder balance, and when the directions of

Cobb's angle, shoulder balance, and trunk balance were identical, the direction of FA was more likely to be the opposite of the direction of VS.

5. Conclusion

With regard both to number of patients with VS and to Cobb's angle, only multi-slice CT scans showed a statistically significant difference between patients with FA and those without FA. Cobb's angle was correlated with menton deviation on multi-slice CT scans, and the direction of FA was opposite that of VS. Our findings suggest that the evaluation of VS is needed in the analysis of and treatment planning for FA in patients who have both FA and VS.

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Tables

Table 1. Abbreviations of nine landmarks

Landmark	Abbreviation	Description
Orbitale	Or	Deepest point on infraorbital margin
Nasion	Na	Middle point of the nasofrontal suture
Porion	Po	Most upper margin of external auditory meatus
Menton	Me	Lowest point on mandibular symphysis
Anterior nasal spine	ANS	Anterior point on nasal spline
Condylion lateralis	Cd^L	Most lateral point of condyle head
Condylion posterius	Cd^P	Most posterior point of condyle head
Gonion lateralis	Go^L	Most lateral point of gonion
Gonion posterius	Go^P	Most posterior point of gonion

Table 2. Abbreviations of parameters

Parameter Abbreviation	Description
∠Cobb	Cobb`s angle
∠Trunk	Coronal trunk balance
∠Shoulder	Shoulder balance
∠Me^{Cep}	Menton deviation in P-A cephalogram
∠Me^{pho}	Menton deviation in clinical photo
∠NaMe	Menton deviation in multi-slice CT
∠NaANS	Deviation of ANS
∠Yaw	Mandibular yawing
∠FRa	Frontal ramal angle
∠PRa	Posterior ramal angle
Cd-Go	Mandibular ramus length
Me-Go	Mandibular body length
ΔFRa	The difference between Rt. and Lt. value of ∠Fra
ΔPRa	The difference between Rt. and Lt. value of ∠PRa
ΔCd-Go	The difference between Rt. and Lt. value of Cd-Go
ΔMe-Go	The difference between Rt. and Lt. value of Me-Go

Table 3. Methodical errors (n = 20).

Parameters	Dahlberg`s error
∠Cobb	0.985
∠Shoulder	0.479
∠Trunk	0.371
∠Me^{Cep}	0.449
∠Me^{Pho}	0.970
∠NaMe	0.275
∠Yaw	0.745
∠NaANS	0.586
ΔFRA	0.780
ΔPRA	0.955
ΔMe-Go	0.635
ΔCd-Go	0.729

The methodical errors were calculated with the common formula for the middle square error: $S^2 = \Sigma d^2/2n$ (d, difference between the first and second measurement; n, number of double measurements).

Table 4. Mean values and statistical analysis of parameters for spinal deviation and FA in clinical facial photography (Photo), CT, P-A cephalogram (Ceph) between FA and non-FA group (*n* = 30). 30 patients were differently classified as FA or non-FA in three image tools, depending on the amount of menton deviation in three image tools.

Parameters	Image tools for FA/non-FA determination					
	Photo		CT		Ceph	
	FA group	non-FA group	FA group	non-FA group	FA group	non-FA group
∠NaMe	2.84±2.0*	1.58±1.2*	4.45±1.2*	0.77±0.5*	3.53±2.3*	1.18±0.7*
∠Me^{Cep}	2.60±2.3*	1.39±1.0*	3.50±1.7*	1.32±1.1*	4.21±1.3*	0.42±0.4*
∠Me^{Pho}	3.17±1.1*	0.55±0.3*	2.67±1.7*	1.29±0.9*	2.81±1.7*	1.52±0.9*
∠Cobb	8.38±3.5	8.25±6.6	9.96±7.1*	5.86±2.0*	6.88±3.8	7.11±3.2
∠Shoulder	1.52±1.0	1.44±0.9	1.57±1.1	1.61±10	1.56±0.9	1.64±1.3
∠Trunk	1.02±0.7	0.63±0.3	1.13±0.6	0.81±0.6	0.84±0.7	0.88±0.7
∠Yaw	3.30±2.2*	2.25±1.0*	4.62±1.6*	1.52±1.1*	4.30±2.2	1.84±1.5
∠NaANS	1.61±1.3*	1.93±1.3*	2.43±1.4	1.07±1.0	2.34±1.6	1.17±1.0
ΔFRA	4.86±4.6*	4.47±2.9*	7.55±4.0*	2.67±1.8*	6.50±4.5	2.22±1.5
ΔPRA	2.27±1.7*	2.35±1.5*	1.50±1.1	2.02±1.5	2.15±1.7	1.77±1.6
ΔMe-Go	1.35±1.0*	1.53±0.8*	2.14±1.1	1.03±0.5	1.81±1.2	1.06±0.6
ΔCd-Go	2.91±30	2.72±1.9	3.47±3.3	2.21±1.5	3.27±3.3	2.43±1.8

*Significance using independent T-test ($P < 0.05$).

Ceph, P-A cephalogram

Photo, clinical facial photography

Table 5. Pearson correlation coefficients among parameters for spinal deviation and FA (n = 30).

Parameter	Method for FA determination		
	CT	Ceph	Photo
∠Cobb	-	.440*	-
∠NaMe	-	.573**	.481**
∠Me^{Cep}	.573**	-	.386*
∠Me^{Pho}	.481**	.386*	-
∠NaANS	.610**	-	-
∠Yaw	.763**	.558**	-
ΔFRA	-	.494**	-
ΔPRA	-	-	-
ΔMe-Go	.535**	-	-
ΔCd-Go	-	-	-

*Significance using Pearson correlation analysis

*. $P < 0.05$

**. $P < 0.01$

Ceph, P-A cephalogram

Photo, clinical facial photography

Table 6. Mean values of three parameters for spinal deviations in total patients, VS and non-VS groups diagnosed in whole spinal standing anteroposterior X-ray.

Patients	Spinal deviation		
	∠Cobb	∠Shoulder	∠Trunk
Total (n = 171)	7.41±3.6	1.61±1.1	0.84±0.6
VS (n = 30)	13.16±3.4*	1.95±1.3	1.06±0.7*
Non-VS (n = 141)	6.19±2.1*	1.54±1.1	0.79±0.6*
*P	0.04	0.07	0.03

*Significance using independent T-test ($P < 0.05$).

Table 7. FA in total patients, VS and non- VS groups diagnosed in whole spinal standing anteroposterior X-ray.

Patients	Menton deviation		FA in CT		FA in Ceph	
	∠NaMe	$\angle Me^{Cep}$	n of FA	% of FA	n of FA	% of FA
Total (*n* = 171)	2.44±1.9	2.18±1.8	57	33.30%	43	25.20%
VS (*n* = 30)	3.13±1.9 *	2.75±2.0	14	46.70%	9	30.00%
Non-VS (*n* = 141)	2.29±1.8 *	2.06±1.8	43	30.50%	34	30.50%
P	*P=0.04	*P=0.08	#P=0.09		#P=0.49	

*Significance using independent T-test ($P < 0.05$).

#Significance using χ^2 test ($P < 0.05$).

Ceph, P-A cephalogram

Table 8. Mean values of parameters for spinal deviation in FA group and non-FA group diagnosed in CT. The data of intermediate group ($n = 43$) were excluded in the comparison between FA and non-FA groups.

Patients	Scoliosis		Spinal deviation		
	N	%	∠Cobb	∠Shoulder	∠Trunk
Total ($n = 171$)	30	17.54%	7.41±3.6	1.61±1.1	0.84±0.6
FA ($n = 57$)	14$^{\#}$	24.56%	8.01±4.4*	1.71±1.3	0.85±0.6
Non-FA ($n = 71$)	8$^{\#}$	11.11%	6.62±2.8*	1.6±1.0	0.9±0.7
P	$^{\#}P$=0.04		$^{*}P$=0.03	$^{*}P$=0.60	$^{*}P$=0.70

*Significance using independent T-test ($P < 0.05$).

$^{\#}$Significance using χ^2 test ($P < 0.05$).

Table 9. Mean values of parameters for FA in FA group and non-FA group diagnosed in CT. The data of intermediate group (*n* = 43) were excluded in the comparison between FA and non-FA groups.

Patients	Ceph	CT						
	∠Me^{Cep}	∠NaMe	∠Yaw	∠NaANS	ΔFRA	ΔPRA	ΔMe-Go	ΔCd-Go
Total (n=171)	2.18±1.8	2.44±1.9	3.00±2.25	1.79±1.4	4.92±4.4	2.49±3.4	1.59±2.1	2.56±3.9
FA (n=57)	3.56±2.1*	4.70±1.2*	5.32±1.88*	2.51±1.6*	7.72±4.5*	2.54±1.9	2.2±3.1*	3.65±5.6*
Non-FA (n=71)	1.42±1.1*	0.76±0.5*	1.40±1.06*	1.18±0.9*	2.91±2.0*	2.58±4.8	1.3±1.0*	2.00±1.8*
**P*	<0.001	<0.001	<0.001	<0.001	<0.001	0.96	0.02	0.02

*Significance using independent T-test ($P < 0.05$).

Ceph, P-A cephalogram

Table 10. Mean values of parameters for spinal deviation in FA group and non-FA group diagnosed in P-A cephalogram. The data of intermediate group (n = 52) were excluded in the comparison between FA and non-FA groups.

Patients	Scoliosis		Spinal deviation		
	N	%	∠Cobb	∠Shoulder	∠Trunk
Total (n = 171)	30	17.54%	7.41±3.6	1.61±1.1	0.84±0.6
FA (n = 43)	9	20.93%	7.52±3.7	1.6±0.9	0.83±0.6
Non-FA (n = 76)	8	10.53%	7.09±2.9	1.54±1.2	0.83±0.7
P	$^{\#}P$=0.10		$^{*}P$=0.49	$^{*}P$=0.78	$^{*}P$=0.97

*Significance using independent T-test ($P < 0.05$).

$^{\#}$Significance using χ^2 test ($P < 0.05$).

Table 11. Mean values of parameters for FA in FA group and non-FA group diagnosed in P-A cephalogram. The data of intermediate group (*n* = 52) were excluded in the comparison between FA and non-FA groups.

Patients	Ceph	CT						
	∠Me^{Cep}	∠NaMe	∠Yaw	∠NaANS	ΔFRa	ΔPRa	ΔMe-Go	ΔCd-Go
Total (*n* = 171)	2.38±1.9	2.62±1.9	3.20±2.4	1.85±1.4	5.22±4.6	2.40±1.9	1.66±2.2	2.78±4.3
FA (*n* = 43)	4.80±1.3*	4.27±2.0*	5.30±2.3*	2.13±1.6	7.72±6.6*	3.04±2.0*	1.62±1.6	4.17±6.8*
Non-FA (*n* = 76)	0.66±0.5*	1.71±1.4*	2.03±1.7*	1.92±1.4	3.88±2.9*	1.89±1.5*	1.33±1.1	2.06±2.0*
**p*	<0.001	<0.001	<0.001	0.29	<0.001	<0.001	0.19	0.01

*Significance using independent T-test ($P < 0.05$).

Ceph, P-A cephalogram

Table 12. Pearson correlation coefficients among parameters for spinal deviation and parameters for FA in P-A cephalogram and CT. (n = 171).

	∠Cobb	∠Me^{Cep}	∠NaMe	∠Yaw	ΔMe-Go
∠Cobb	-	-	.169*	-	
∠Me^{Cep}	-	-	.579**	.619**	-
∠NaMe	.169*	.579**	-	.810**	.153**
∠NaANS	-	-	.471**	.295**	
∠Yaw	-	.657**	.831**	-	.297**
ΔFRa	-	.36**	.527**	.264**	.231**
ΔPRa	-	.249**	-	.203*	.178*
ΔMe-Go	-	-	.153**	-	-
ΔCd-Go	-	.197**	.199**	-	.282**

*Significance using Pearson correlation analysis

*. $P < 0.05$

**. $P < 0.01$

Table 13. The direction of Cobb`s angle, shoulder balance and trunk balance according to the direction of FA.

	Direction of FA		∠Cobb		∠Shoulder		∠Trunk	
			Rt.	Lt.	Rt.	Lt.	Rt.	Lt.
Total	Rt	109	38	71	59#	42#	39	66
(*n* = 171)	Lt	62	28	34	44#	16#	29	30
#*P*			0.19		0.03		0.19	
κ			-0.102		-0.165		-0.108	

#Significance using χ^2 test ($P < 0.05$).

Table 14. The direction of FA and VS in the patients when the direction of Cobb`s angle, shoulder balance and trunk balance were identical (n = 52).

Direction of FA	Direction of scoliosis	
	Rt.	Lt.
Rt. (n = 30)	10#	20#
Lt. (n = 22)	15#	7#
#P	0.02	
κ	-0.338	

#Significance using χ^2 test ($P < 0.05$).

Figure legends

Figure 1. Evaluation FA in P-A cephalogram (A) and clinical facial photography (B).

(A) Horizontal reference line was drawn as the line between latero-orbitale point, and a vertical reference line was made as the perpendicular line to horizontal reference point passing by crista galli. Vertical midpoint reference line was set as the line between the crista galli and menton. The angle between the vertical reference line and the vertical midpoint reference line was defined as $\angle Me^{Cep}$.

(B) The interpupillary line was drawn as a horizontal reference line and the line perpendicular to horizontal reference line was set as a vertical reference line. Vertical midpoint reference line was set between the center of soft tissue nasion and menton. The angle between V-midline and V-line in clinical facial photography was defined as $\angle Me^{Pho}$.

Figure 2. 15 landmarks (3 single and 6 paired landmarks) and 3 reference planes for the evaluation FA in CT.

Figure 3. Definitions of landmarks and measurements of angular and linear parameters for FA in CT

(A) ∠NaMe: The angle between the midsagittal plane and the line connecting Na and Me.
∠NaANS: The angle between the midsagittal plane and the line connecting Na and ANS.

(B) ∠FRA: The angle between the midsagittal plane and the line connecting Cd^L (condylion lateralis) and Go^L (gonion lateralis) on the right and left side
Cd-Go on the right and left side: The distance between Cd^L and Go^L on the right and left side

(C) ∠Yaw: The angle between the midsagittal plane and the line connecting Me and the midpoint of both Go^L.
Me-Go on the right and left side: The distance between Me and Go^L on the right and left side.

(D) ∠PRA on the right and left side: The angle between the coronal plane and the line connecting Cd^P (condylion posterius) and Go^P (gonion posterius) on the right and left side

Figure 4. Measurements of Cobb`s angle, coronal trunk balance and shoulder balance in whole-spine standing anteroposterior radiography

(A) Cobb's angle: the angle between the parallel line to the superior vertebral end plate and the parallel line to the inferior vertebral end plate of the most tilted vertebra at the spinal curve. If Cobb`s angle is greater than or equal to 10 degrees, it was defined scoliosis.

(B) Coronal trunk balance: the angle between the center sacral line and the C7-S1 line. The center sacral line is the line crossing the center of the sacrum and the C7-S1 line is the line between midpoint of C7 and Spinous process of S1.

(C) Shoulder balance: the angle between the horizontal reference line and the line connecting both shoulder peak. The horizontal reference line is the line perpendicular to the gravity line and the point of shoulder peak is most superior point of the clavicle.

Figure 5. Mean values of the parameters for VS and FA in FA group and non-FA group diagnosed in CT (A) and P-A cephalogram (B). The data of intermediate group were excluded in the comparison between FA and non-FA groups. *Significance using independent T-test ($P<0.05$), #Significance using χ^2 test ($P<0.05$).

Figure 6. The correlation between the menton deviation and Cobb`s angle.

Figure 7. Relation between the direction of FA and VS. The contralateral direction of facial asymmetry compared to the direction of vertebral scoliosis.

Figure 8. Angular deviations of FA in CT (red lines) and P-A cephalogram (purple lines) and angular deviations of VS with Cobb`s angle (purple lines), coronal trunk balance (red lines) and shoulder balance (yellow lines) in whole-spine standing anteroposterior radiography in 4 cases

Figures

Figure 1.

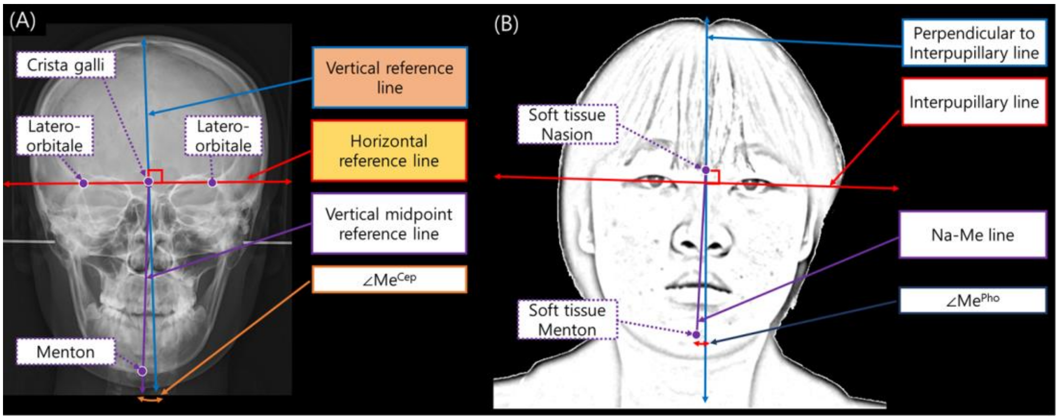


Figure 2.

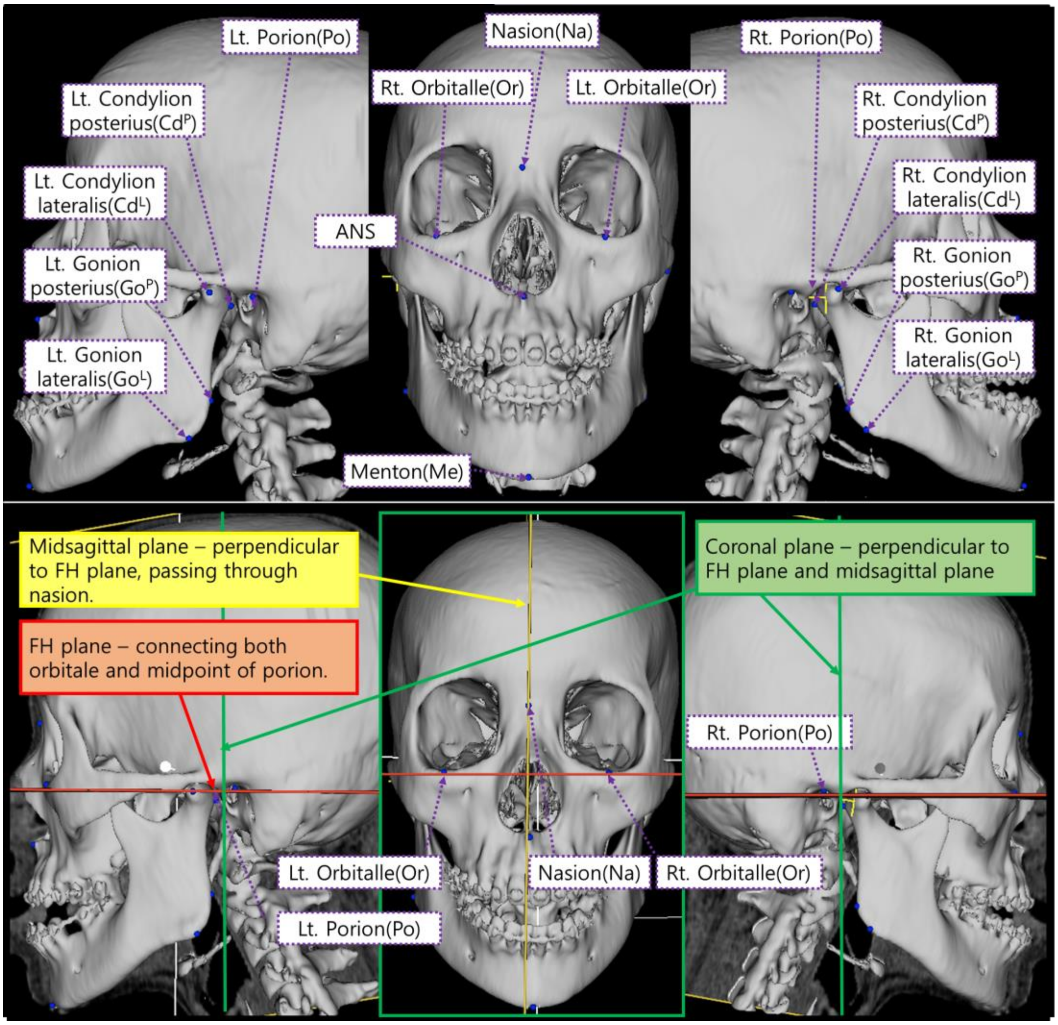

Lt. Porion(Po)
Nasion(Na)
Rt. Porion(Po)
Rt. Orbitalle(Or)
Lt. Orbitalle(Or)
Lt. Condylion posterius(Cd^P)
Rt. Condylion posterius(Cd^P)
Lt. Condylion lateralis(Cd^L)
Rt. Condylion lateralis(Cd^L)
ANS
Lt. Gonion posterius(Go^P)
Rt. Gonion posterius(Go^P)
Lt. Gonion lateralis(Go^L)
Rt. Gonion lateralis(Go^L)
Menton(Me)
Midsagittal plane – perpendicular to FH plane, passing through nasion.
Coronal plane – perpendicular to FH plane and midsagittal plane
FH plane – connecting both orbitale and midpoint of porion.
Rt. Porion(Po)
Lt. Orbitalle(Or)
Nasion(Na)
Rt. Orbitalle(Or)
Lt. Porion(Po)

Figure 3.

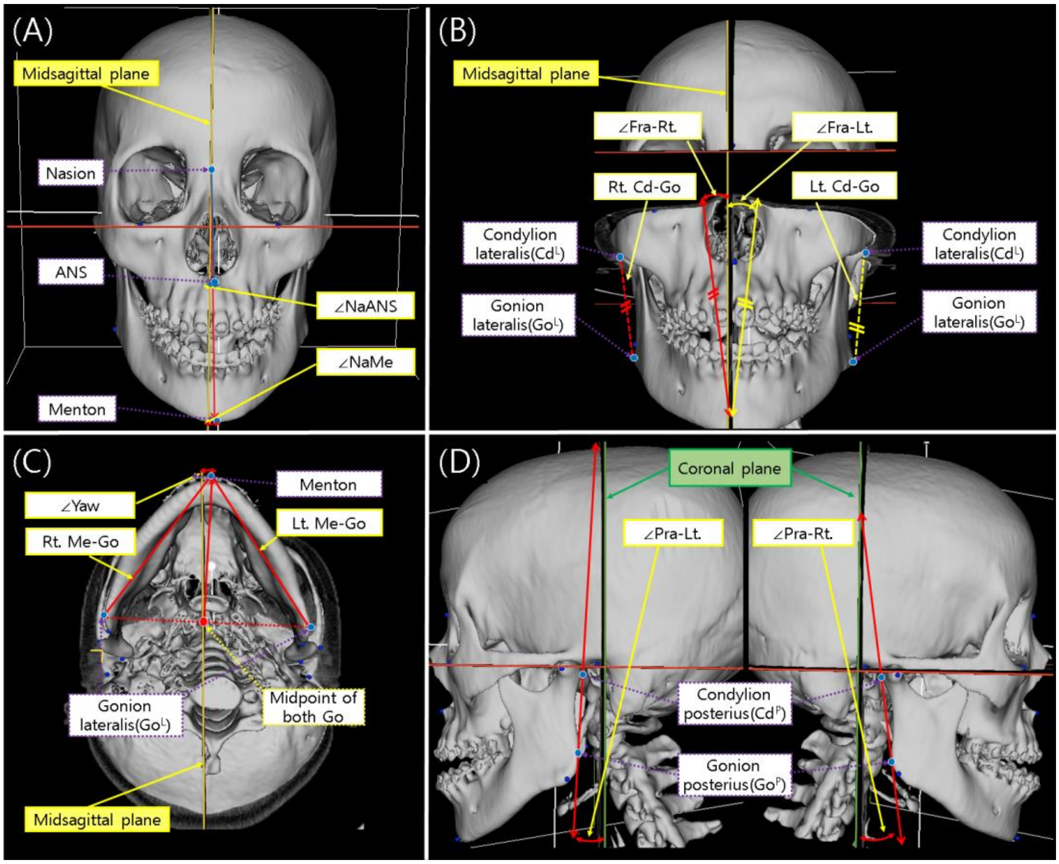
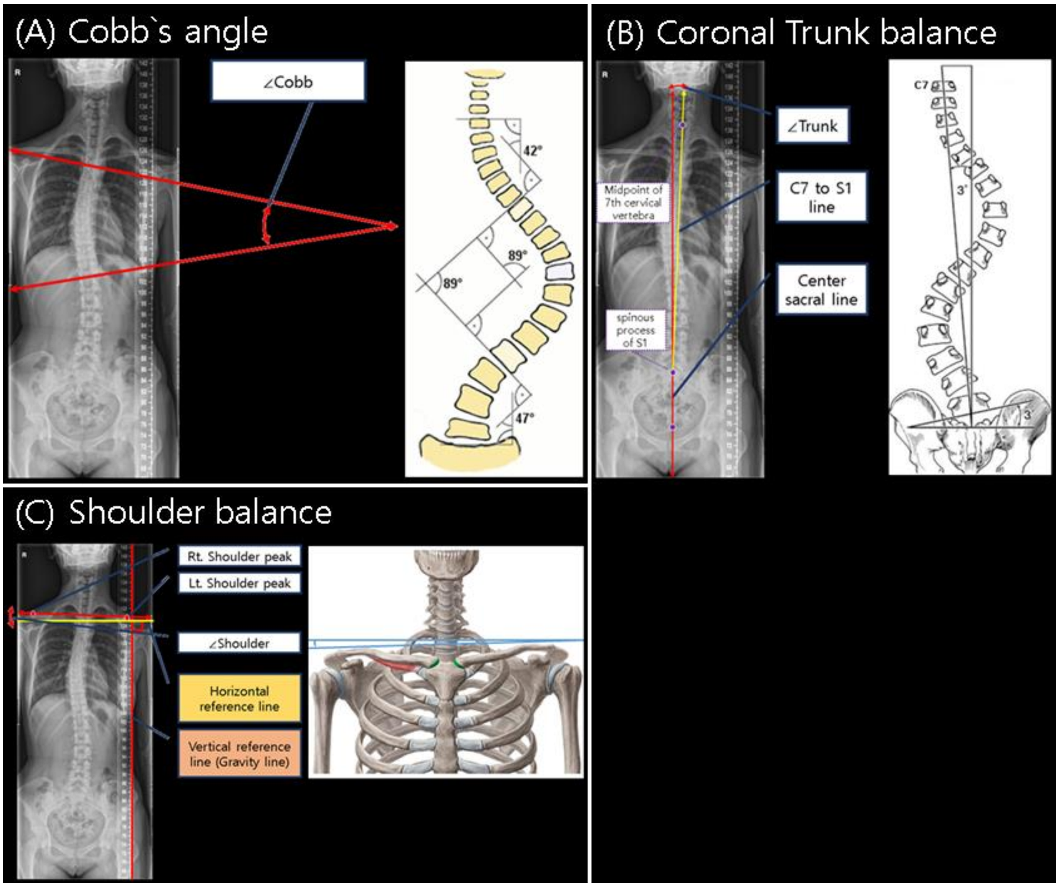

(A)
Midsagittal plane
Nasion
ANS
∠NaANS
∠NaMe
Menton
(B)
Midsagittal plane
∠Fra-Rt.
∠Fra-Lt.
Rt. Cd-Go
Lt. Cd-Go
Condylion lateralis(Cd^L)
Condylion lateralis(Cd^L)
Gonion lateralis(Go^L)
Gonion lateralis(Go^L)
(C)
Menton
∠Yaw
Lt. Me-Go
Rt. Me-Go
Gonion lateralis(Go^L)
Midpoint of both Go
Midsagittal plane
(D)
Coronal plane
∠Pra-Lt.
∠Pra-Rt.
Condylion posterius(Cd^P)
Gonion posterius(Go^P)

Figure 4.



(A) Cobb`s angle
∠Cobb
42°
89°
89°
47°
(B) Coronal Trunk balance
∠Trunk
Midpoint of 7th cervical vertebra
C7 to S1 line
Center sacral line
spinous process of S1
C7
3°
3°
(C) Shoulder balance
Rt. Shoulder peak
Lt. Shoulder peak
∠Shoulder
Horizontal reference line
Vertical reference line (Gravity line)

Figure 5.

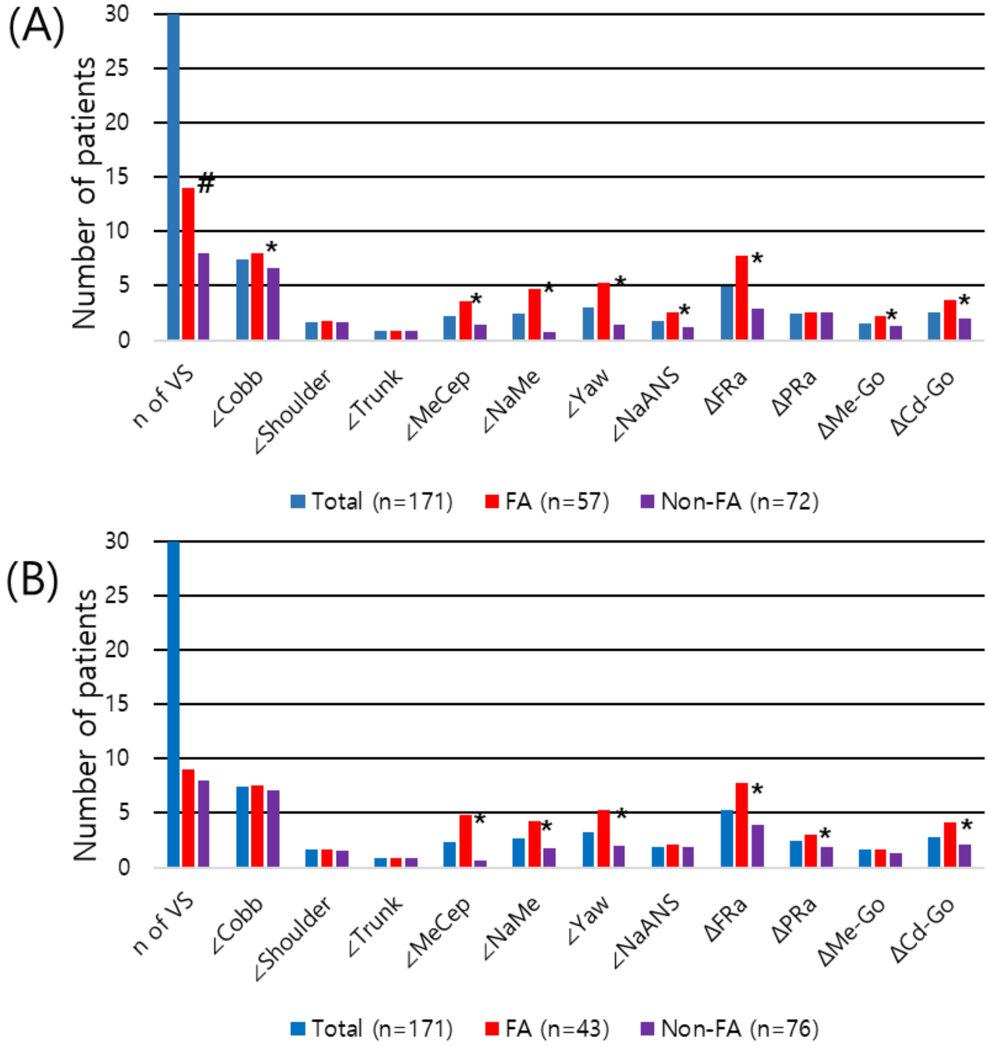

(A)
Number of patients
30
25
20
15
10
5
0
#
*
n of VS
∠Cobb
∠Shoulder
∠Trunk
∠MeCep
∠NaMe
∠Yaw
∠NaANS
ΔFRa
ΔPRa
ΔMe-Go
ΔCd-Go
Total (n=171)
FA (n=57)
Non-FA (n=72)
(B)
Number of patients
Total (n=171)
FA (n=43)
Non-FA (n=76)

Figure 6.

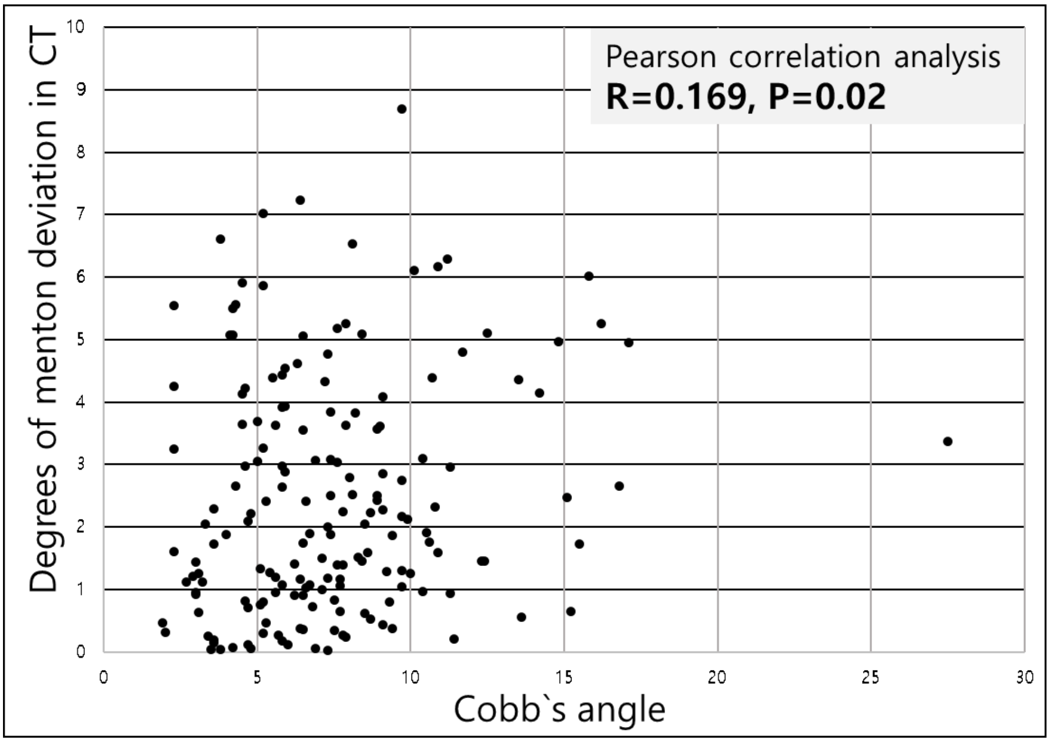

Pearson correlation analysis
R=0.169, P=0.02
Degrees of menton deviation in CT
Cobb`s angle
0
1
2
3
4
5
6
7
8
9
10
0
5
10
15
20
25
30

Figure 7.

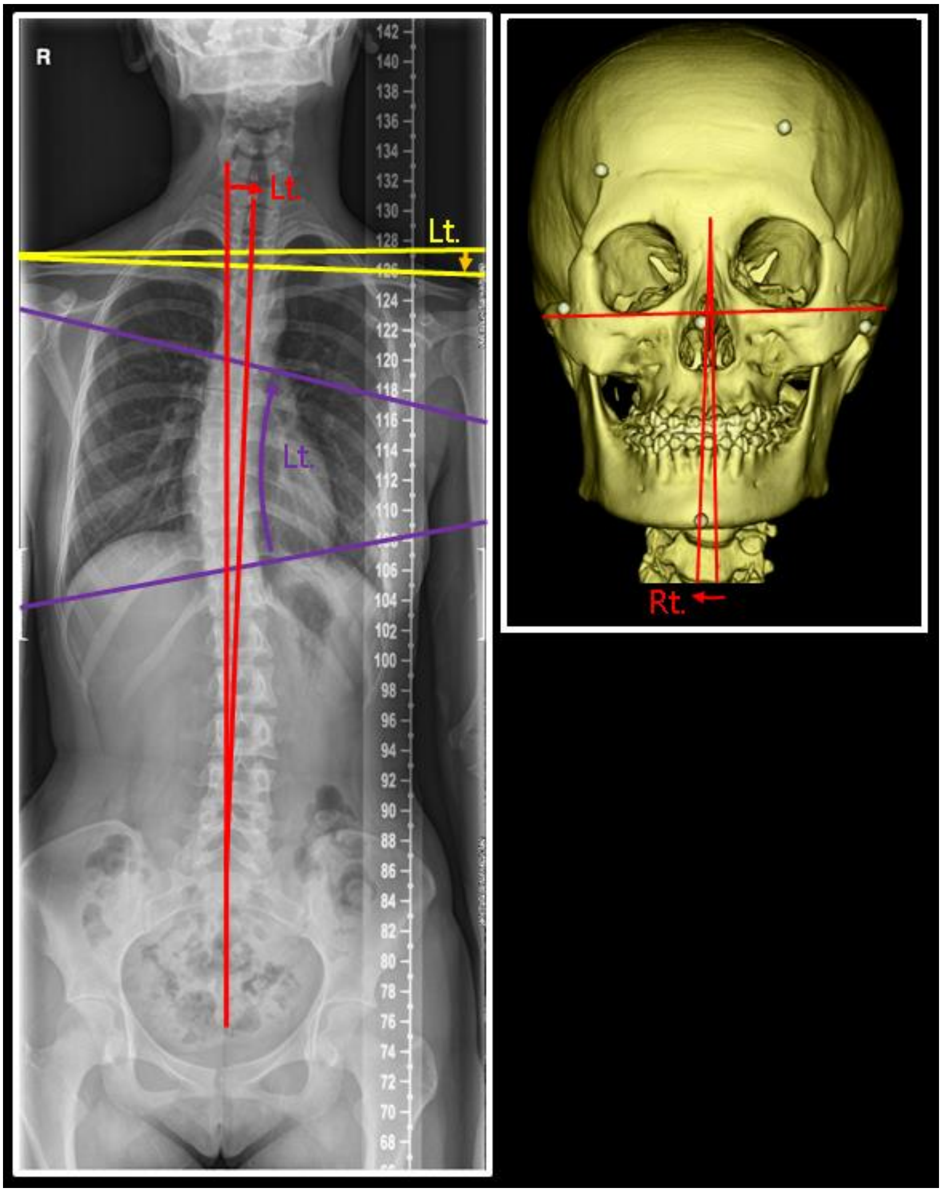
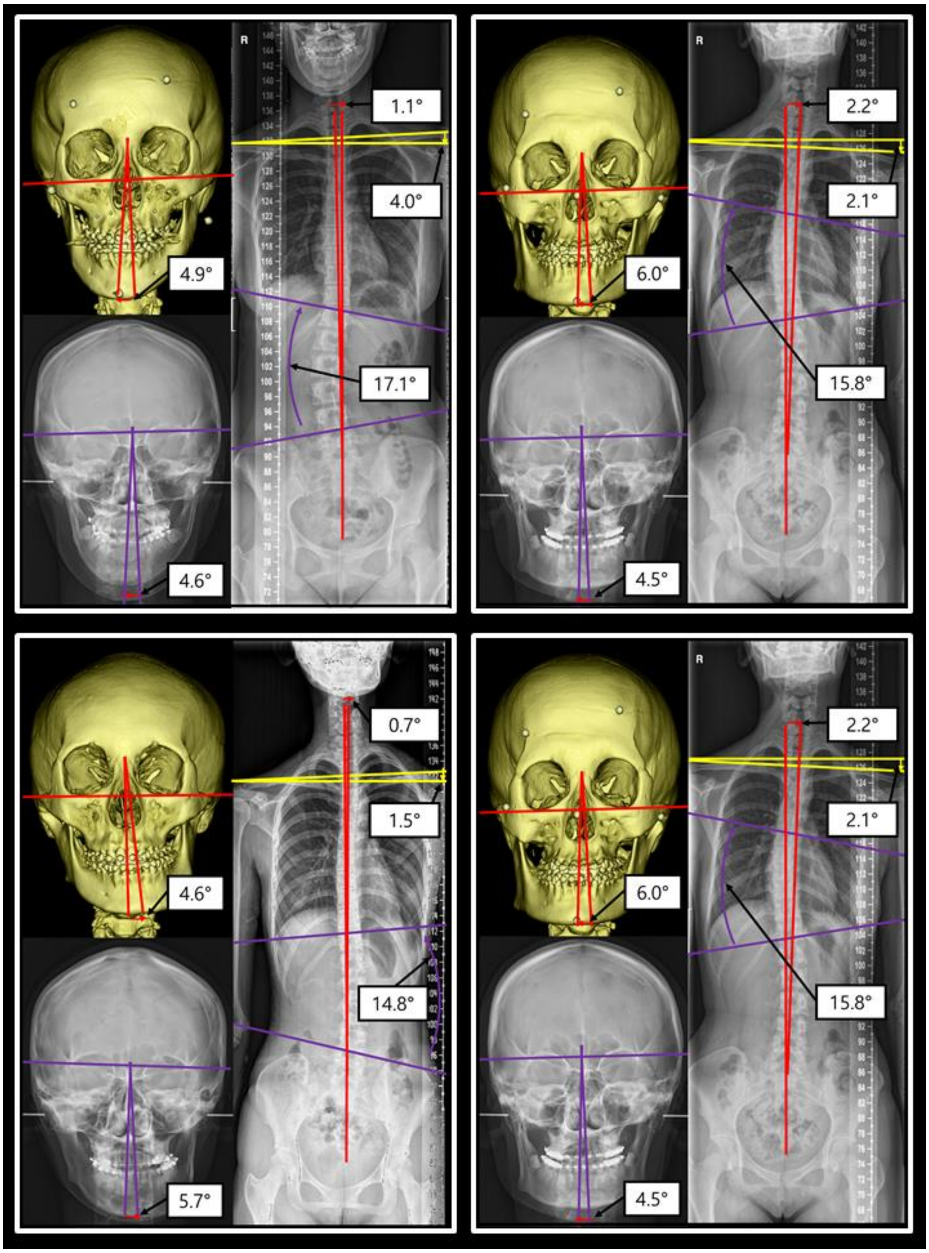


Figure 8.



-국문 초록-

안면 비대칭 유무에 따른 척추 측만증 및 척추 만곡 정도의 비교

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연구목적: 안면 비대칭과 척추 측만증을 포함한 척추 만곡은 각각 구강 악안면 부위와 전신에 생기는 흔한 기형의 하나이다. 둘 간의 연관성에 대해서는 소수의 연구가 있었지만 일치된 결과가 나오지는 않았다. 본 연구에서는 컴퓨터 단층 영상, 임상 사진, 전후방 두부 방사선 계측 사진을 이용하여 둘 간의 관계를 평가하고자 하였다.

연구 대상 및 방법: 총 171 명의 환자에 대하여 각각 컴퓨터 단층 영상, 임상 사진, 전후방 두부 방사선 계측 사진 상에서 menton의 변위를 측정하여 안면 비대칭을 평가 및 분류하였다. 안면 수직선에

대한 menton 변위가 3도보다 큰 환자들은 비대칭 그룹, 1.5도보다 작은 환자들은 비대칭그룹으로 구분하였고, 1.5도에서 3도 사이의 변위를 보인 환자들은 중간그룹으로 간주하고 비대칭군과 대칭군의 비교 평가에서 제외하였다. 또한 이들에 대하여 전 척추 전후방 방사선 사진 상에서 척추 측만증 및 척추 만곡과 관련된 3 개의 변수 (∠Cobb, ∠Shoulder, ∠Trunk)들을 측정하고 컴퓨터 단층영상에서 안면 비대칭과 관련된 6개의 변수 (∠Yaw, ∠NaANS, ⊿FRa, ⊿PRa, ⊿Me-Go, ⊿Cd-Go)들을 측정하여 통계적으로 분석하였다.

결과: 전후방 두부 방사선 계측에서 43명의 환자가 안면 비대칭을 보였고, 76명은 비대칭이 없었다. 비대칭군에서 9명 (20.9%)의 척추 측만증 환자가 있었으며, 콥스 씨 각도는 7.52 ± 3.74° 이었다. 비대칭이 없는 군에서는 8명 (10.5%)의 환자가 척추 측만증을 보였으며, 콥스 씨 각도는 7.09 ± 2.89° 이었다. 하지만, 척추 측만증 환자 수나 콥스 씨 각도의 두 환자군에서의 비교는 통계적으로 유의미하지 않았다. 컴퓨터 단층 영상을 기준으로 분석한 결과 57명의 안면 비대칭 환자와 71명의 안면 비대칭이 없는 환자로 분류되었다. 각 대상군에서 척추 측만증 환자는 각각 14명 (24.6%)과 8명 (11.1%)이고 콥스 씨 각도의 평균은 각각 7.41 ± 3.6°와 6.62 ± 2.8°로 분석되었으며 두 항목은

통계적으로 유의미한 차이를 나타냈다 (각각 P = 0.04 와 0.03). 콥스 씨 각도는 안면 비대칭의 평가 항목 중 ∠NaMe와 통계적으로 유의미한 상관관계를 갖는 것으로 나타났고 (R = 0.169, P = 0.02), 안면 비대칭의 방향은 어깨 균형의 방향과 반대 방향으로의 일치도를 나타냈으며 (P = 0.03, κ =−0.165), 어깨 균형, 관상 몸통 균형, 척추 만곡의 방향이 일치하는 환자들의 경우는 반대 방향으로의 일치도가 더 크게 나타났다 (P = 0.02, κ = −0.338).

결론: 안면 비대칭이 있는 군과 없는 군의 비교에서 컴퓨터 단층촬영 이미지를 이용한 분석에서만 척추 측만증 환자의 수와 척추 만곡의 정도가 유의하게 차이가 있었다. 컴퓨터 단층촬영 이미지를 이용한 분석에서 척추 만곡의 정도 (콥스 씨 각도)는 턱끝 (menton)의 변위와 유의한 상관관계를 보였으며 안면 비대칭의 방향은 척추 측만증 방향과 반대 방향으로의 일치도를 보였다. 본 연구 결과는 안면 비대칭의 평가 및 치료계획 수립에서 척추 측만증에 대한 평가를 동반할 필요가 있음을 제시한다.

주요어 : 안면 비대칭, 척추 측만증, 어깨 균형, 관상 몸통 균형, 상관관계