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Analysis of the relationship between the morphology of the palate and facial skeletal patterns in Class III malocclusion using structural equation modelling

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Structured Abstract

Introduction: The present study investigated the relationship between facial skeletal patterns and morphology of the palate in adult patients with Class III malocclusion using structural equation modelling (SEM).

Setting and sample population: One hundred cone beam computed tomography images of Class III adults were evaluated for skeletal measurements.

Materials and methods: The skeletal measurements were classified into the vertical, anteroposterior and transverse group based on factor analysis. 3D scanning model of the maxilla was analysed by Generalized procrustes analysis (GPA) and principal component analysis (PCA). Structural equation modelling was used to analyse relationship among the skeletal and morphometric factors.

Results: According to the factor analysis, latent variables were extracted by each skeletal variable. First principal component (PC1) and PC2 of palatal morphology were used to analyse relationship with skeletal variables. As results of the structural equation model, the transverse latent variable had the most influence on PC1, followed by vertical and anteroposterior variables. This result means that as the facial width increases, the palate becomes narrower, deeper and longer.

Conclusions: The relationship between the skeletal pattern with Class III malocclusion and palatal morphology was analysed through SEM. The transverse facial skeletal pattern showed the highest correlation with PC1 of palatal morphology.

KEYWORDS
facial pattern, palatal shape, structural equation model

1 | INTRODUCTION

The palate plays an important role in functions, and its morphology is influenced by oral habits such as mouth breathing.[1,2] Additionally, the palatal shape has been reported to be related to various skeletal patterns. High and narrow palatal shape is often observed with hyperdivergent skeletal pattern, while low and broad palatal shape is observed to be associated with hypodivergent skeletal pattern.[3,4]

Skeletal malocclusion is manifested in the anteroposterior position and morphological differences of the maxilla and mandible. Among skeletal malocclusion, skeletal Class III malocclusion shows maxillomandibular disharmony and its palatal shape is distinguishable from the other skeletal pattern and the orthodontic treatment plan should be reflected narrow palatal widths.[5]

Furthermore, the maxillofacial skeletal pattern seems to be correlated to horizontal as well as vertical factors. A narrow transverse skeletal pattern is observed with a hyperdivergent skeletal pattern, whereas a wider transverse skeletal pattern is observed with a hypodivergent skeletal pattern.[6,7] As reported in previous studies, vertical and transverse skeletal pattern are closely related. Nonetheless, there is little analysis of the relationship between these three components and palatal shape in Class III malocclusion patients.

For skeletal measurements, cone beam computed tomography improves the accuracy of landmarks and reduces potential errors.[8] Like the skeletal measurement, analysing the palatal shape through 3D laser scanning has aided in high-speed measurement with high accuracy.[9] The morphological variations are visualized and analysed by geometric morphometric analysis.[10,11]

Structural equation modelling (SEM) can be used to analyse the relationship between various factors from the skeletal pattern and palatal morphology. This statistical technique simplify the relationship of multiple factors and make it possible to express the results in a schematic manner to help achieve an overall understanding. Additionally, it can be used to evaluate the fitness and validity of the research model.[12]

The purpose of this study was to extrapolate the existing 2D skeletal analysis to 3D and visualize the relationship between the craniofacial skeletal pattern and palatal shape, using SEM. In brief, (a) the palatal shape is analysed by geometric morphometric analysis to obtain a 3D landmarks. (b) The morphometric analysis and the craniofacial measurements were dimensionally reduced through factor analysis. (c) A structural equation model is constructed to analyse the relationship between the palatal shape and craniofacial measurements in skeletal Class III malocclusion.

TABLE 1 Definition of the measurement used in this study

Dimension	Measurement	Definition
Transverse	FZ-FZ	Distance between the right and the left FZ
	Or-Or	Distance between the right and the left Or
	ZA-ZA	Distance between the right and the left ZA
	Co-Co	Distance between the right and the left Co
	Go-Go	Distance between the right and the left Go
Vertical	N-Me	Distance between N and Me
	N-ANS	Distance between N and ANS
	S-Go	Distance between Co and Go
	Co-Go	Distance between Co and Go
Anteroposterior	S-N	Distance between S and N
	Ba-N	Distance between Ba and N
	S-A	Distance between S and A
	ANS-PNS	Distance between ANS and PNS
	S-B	Distance between S and B
	Go-Gn	Distance between Go and Gn

A, point A; ANS, anterior nasal spine; Ag, antegonion; B, point B; Ba: basion; Co, condylion; FZ, frontozygomatic point; Gn, gnathion; Go, gonion; N, nasion; Or, orbitale; Pg, pogonion; PNS, posterior nasal spine; Po, porion; S, sella; ZA, zygomatic arch.

2 | MATERIALS AND METHOD

2.1 | Study sample

A hundred adult patients (60 males, 40 females, mean age 22.12 ± 3.86 years) who visited 0000 Dental Hospital from January 2010 to October 2017 and were diagnosed to have skeletal Class III malocclusion were included. The inclusion criteria were as followed: negative ANB (mean −3.84 ± 1.9°), increased mandibular length (mean range 84.0 ± 5.0 mm and 80.0 ± 5.0 mm for the male and female) with respect to the norm, large anterior facial height (mean range 138.0 ± 7.0 mm and 128.0 ± 6.0 mm for the male and female), negative wits appraisal (mean −11.26 ± 5.84) and the absence of forward displacement of the mandible. Patients with systemic disease, trauma, history of surgery, and cleft lip and palate were excluded from this study. CBCTs were taken for preoperative evaluation of orthognathic surgery or surgical extraction of the impacted tooth. This study was reviewed and approved by the institutional review board of 0000 Hospital (PNUDH-2017-035).

2.2 | Study method

In this study, structural equation model was used to determine the relationship between skeletal patterns and palatal shapes. First, measurements of the skeletal pattern and the palate were obtained. Factor analysis was performed on observed variables to extract latent variables. Structural equation model was constructed to evaluate the relationships of latent variables.

2.3 | CBCT scan and image acquisition

The patients were scanned using CBCT (Zenith3D; Vatech Co., Seoul, Korea) under the same conditions (90 Kvp; 10 mA, scan

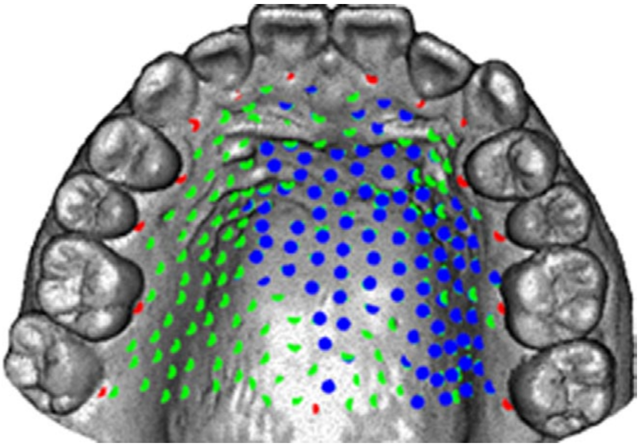

FIGURE 1 Surface landmarks and semi-landmarks used for the description of palatal morphology. Red points indicate landmarks of the gingival margin on the palatal surface. Fourteen points are placed on the midpoint of the palate-gingival margin of the maxillary teeth, and one point is placed on the intersection of the mid-palatal suture and a line connecting a midpoint of the maxillary second molar; green points indicate semi-landmarks of the model of the subjects; blue points indicate semi-landmarks of the template

time 24 seconds; voxel size, 0.3 mm; FOV 20 × 19 cm). To process 3D craniofacial skeletal morphology, 3D imaging software (InVivo; Anatomage Inc., San Jose, CA) was used. For facial skeletal measurements, two reference planes were set in this study, and nasion was set as the origin (0, 0, 0). The FH plane and mid-sagittal plane were set as the horizontal and vertical reference plane, respectively.

2.4 | Measurement of craniofacial morphology

The definitions of craniofacial landmarks[13] and measurements are provided in Table 1. Craniofacial morphology was analysed in three different planes—transverse, vertical and anteroposterior. Vertical factors included total facial height, lower anterior facial height, posterior facial height and ramus height. The former two elements are located on the anterior aspect of the face, and the latter two elements are located on the posterior of the face.

Transverse measurements were taken from the orbit, zygomatic arch and the width of the mandible. The width between the zygomaticofrontal suture was set as the distance between the left and right frontozygomatic points, respectively. Inter-zygomatic distance was set based on the landmarks on the zygomatic arch. The width of the mandible was measured at the condyle and the body of the mandible.

Anteroposterior lengths were measured through the maxillofacial complex. The cranial base was measured based on the total cranial base and the anterior cranial base. The maxilla was measured using the anterior nasal spine (ANS) and the posterior nasal spine (PNS). The mandibular length was measured using gnathion as the anterior end and gonion as the posterior end. S-A and S-B were measured to evaluate the length of the maxilla and mandible relative to the cranial base.

2.5 | Shape analysis of the palate

The maxillary study models of the patients were scanned using an intraoral scanner (Trios, 3shape, Copenhagen, Denmark, accuracy 20 μm) to analyse the palatal morphology. R software (version 1.1.442, R foundation for statistical computing, Vienna, Austria) was used to extract landmarks of the palate as the three-dimensional coordinates. The line passing through the centre of the gingival margin of each tooth was set as the boundary of the palate, and the line passing through the centre of the second molar and the palatal centre was set as the posterior boundary. Semi-landmarks were uniformly measured within the boundary of the palatal surface. A total of 200 points were located on the palate (Figure 1).

2.6 | Statistical analysis

2.6.1 | Factor analysis of craniofacial measurements

Skeletal observation variables of 100 patients were classified into three groups. Then, exploratory factor analysis was performed to analyse the relationship between the variables. After the factor extraction process, two latent variables which cumulative proportion was more than 70% were obtained for each group. The transverse latent variables were named transverse 1 and transverse 2, respectively. Likewise, the vertical and anteroposterior latent variables were named the same way as above. The intraclass correlation coefficient for the intra-examiner error was 0.941 (0.966-0.916), and the intra-examiner reproducibility of all measurements was very high.

2.6.2 | Morphometric analysis

The palatal morphology of the three-dimensional model was evaluated by Generalized procrustes analysis (GPA). A total of 200 morphometric points were obtained from the palatal surface, thereby forming the average morphology of the palatal surface. PCA was used to determine the variation of the palatal shape.

2.6.3 | Structural equation modelling

Structural equation modelling (SEM) was used to determine the relationship between skeletal variables and palatal morphologic variations. After evaluating the model, PCs were determined by evaluating the significance of skeletal latent variables. The relationship between the latent variables of the facial skeleton with PC1 and PC2 was analysed by structural equation model, and the fitness of the model was evaluated to verify that it is an appropriate model.

3 | RESULTS

3.1 | Factor analysis of craniofacial morphology

Based on the exploratory factor analysis of 15 skeletal variables, we extracted two factors from the transverse, vertical and anteroposterior variables, respectively. Transverse 1 was associated with the orbital width (ZA-ZA), as well as the mandibular width (Co-Co, Go-Go). Transverse 2 was associated with orbital width (FZ-FZ, Or-Or). Vertical 1 was associated with total facial height (N-Me) and upper facial height (N-ANS), and Vertical 2 was associated with posterior facial height (S-Go) and ramus length (Co-Go). Anteroposterior 1 was related to the total length of cranial base (S-N), posterior cranial base (Ba-N), anteroposterior length of maxilla (ANS-PNS) and S-A. Anteroposterior 2 was related to mandibular body (Go-Gn) and S-B.

Secondary latent variables were obtained by extracting two factors from each group. In order to determine the fitness of the secondary factor model of skeletal measurements, root mean square residual (RMR), root mean square error of approximation (RMSEA), goodness-of-fit index (GFI), adjusted GFI (AGFI), relative fit index (RFI) and incremental fit index (IFI) were used. RMR and RMSEA showed relatively poor results (RMR and RMSEA>0.08), while the other four scales (GFI, AGFI, RFI and IFI) were satisfactory (GFI, RFI and IFI ≥ 0.70; AGFI ≥ 0.69).

3.2 | Morphometric analysis of palatal morphology

The PCA was performed by extracting two hundred 3D morphometric points from each of the palates. As indicated by the result of PCA, it was necessary to secure more than seven PCs in order to obtain the cumulative proportion of variance explained of over 70%. In order to analyse the morphological variation, the three-dimensional shape was divided two-dimensionally. The results of analysing PCs and skeletal variables showed that PC1 and PC2 have significant influence on skeletal measurements (Figure 2). PC1 showed the greatest proportion of variance explained and showed variations in all three dimensions. In the X-Y plane, the width of the entire palate decreased at −3SD and increased at +3SD. In the X-Z plane, the middle one-third of the palate decreased in height at −3SD and increased at +3SD. In the Y-Z plane, the anteroposterior length of palatal 1/3 of the teeth decreased at −3SD and increased at +3SD. In PC2, the fluctuation was mainly observed in the Y-Z plane, and the medial 1/3 and posterior 1/3 of palatal heights were increased at −3SD and were decreased at +3SD.

3.3 | Structural equation model

The relationship between the parameters of the facial skeleton and the PCs of the palatal shape was presented by SEM (Table 2, Figure 3). In order to obtain more than 70% cumulative proportion of variance explained, more than seven PCs were required. However, considering the influence of skeletal variables, it was significant to include principal components 1 and 2 for constructing the model. Among the skeletal latent variables, the vertical and anteroposterior latent variables were significant except for the effect of the transverse latent variable on PC2 of palatal morphology.

As indicated by the result of each influence, transverse latent variable had the greatest influence on PC1, followed by the vertical and anteroposterior latent variables. The effect on PC2 was the highest in the vertical latent variable, followed by the anteroposterior latent variable. The fit of the model was verified using several fitness indexes indices (GFI, RFI and IFI > 0.70; AGFI ≥ 0.66).

4 | DISCUSSION

The skeletal variables were divided into three categories: transverse, vertical and anteroposterior. Factor 1 for the

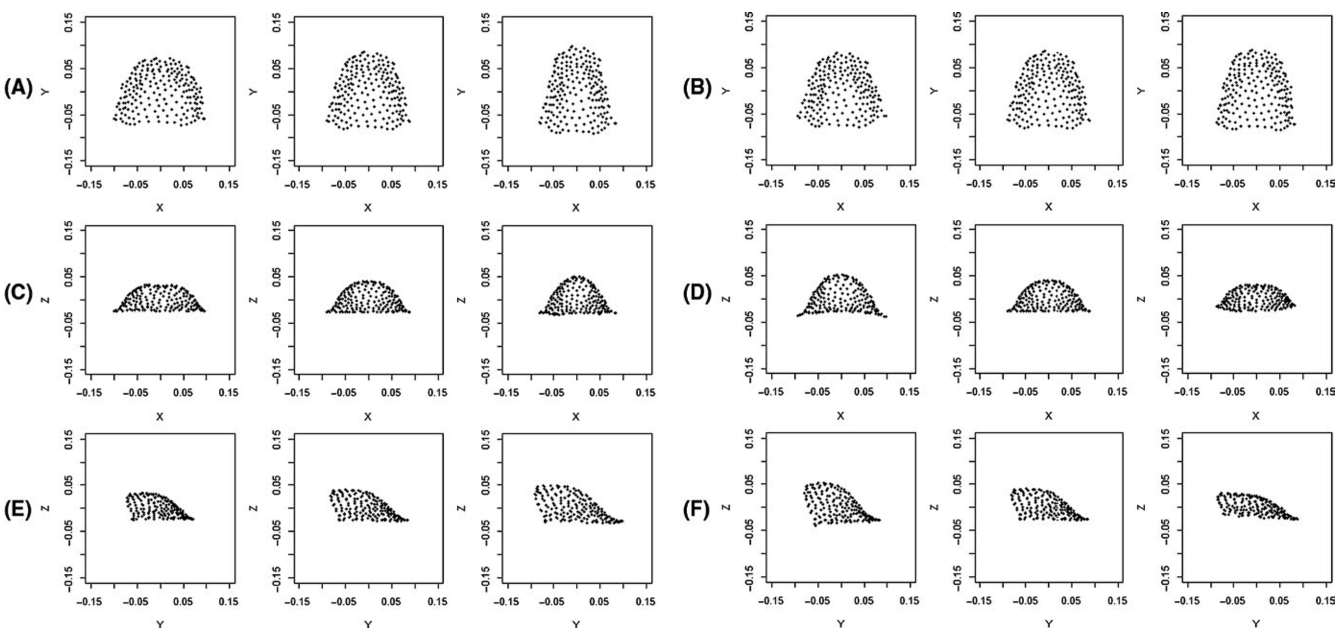

FIGURE 2 First principal component (PC1) of the 3D palatal region by using principal component analysis. (A, B) The palatal morphology was projected on an X-Y horizontal plane. (C, D) The palatal morphology was projected on an X-Z frontal plane. (E, F) The palatal morphology was projected on a Y-Z sagittal plane

TABLE 2 Regression weight

Dependent variable		Independent variable	Estimate	Standard error	Standardized estimate	Critical ratio	*P*-value
PC1	←	Transverse	−0.060	0.024	−1.333	−2.523	0.012
PC1	←	Vertical	0.044	0.022	0.990	2.013	0.044
PC1	←	Anteroposterior	0.027	0.010	0.587	2.637	0.008
PC2	←	Vertical	−0.027	0.006	−0.866	−4.475	<0.01
PC2	←	Anteroposterior	0.015	0.006	0.482	2.393	0.017

PC: principal components.

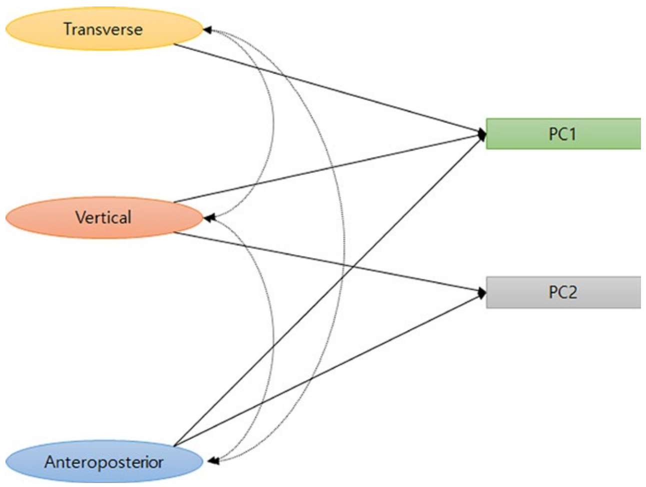

FIGURE 3 Structural equation model of the skeletal measurement and principal components (PCs) of the palatal morphology. The skeletal latent variable (transverse, vertical and anteroposterior variables) showed correlations. The skeletal latent variable was associated with the principle components of palatal morphology (except transverse variable to PC2)

anteroposterior latent variable was associated with the cranial base and the maxilla, while factor 2 consisted of the elements related to the mandible. The two factors appeared to be distinguishable in terms of their relation to other skeletal factors; however, factor 1 and factor 2 did not appear to be associated with specific skeletal sites. Factor 1 was associated with the inferior facial patterns in the transverse latent variable, but it appeared to be associated with the superior facial pattern in the vertical and anteroposterior latent variables. Moreover, factor 2 was associated with the superior facial pattern in the transverse latent variable, but was associated with the mandible in the vertical and anteroposterior latent variables.

Seven PCs were required to obtain more than 70% of shape variance, but only two PCs were used to consider the relationship of the skeletal latent variables. This means that it is not easy to find correlations between three-dimensional landmarks for analysing these relationships. However, the previous studies analysing three-dimensional data into two-dimensional landmarks have the risk of exaggeration of interpretation. In this respect, the structural equation model can simplify the relation of the three-dimensional data through a dimensional reduction and enable the formation of convenient and usable models. This allows for an intuitive understanding of the relationship between latent variables.

The SEM results presented that there is a high correlation between the transverse latent variable and the PC 1 of the palatal shape variation. It was observed that the palatal shape was narrow, deep and long, or was wide, shallow and short, depending on the transverse facial skeletal pattern. In contrast, the anteroposterior latent variable had a low influence on the principal component, in that the variation of the palatal morphology due to the skeletal difference in anteroposterior direction was not significant; that is, even if the posterior facial height is long, its influence on palatal shape variation would not be significant.

The complex relationship indicated by the SEM has important implications for orthodontic treatment of skeletal class III malocclusion. Unfortunately, this study was limited to severe skeletal Class III malocclusion. In severe skeletal class III malocclusion, there may be an increase of the anteroposterior length of the mandible and the vertical facial height than mild skeletal class III malocclusion. Although these factors did not directly affect the results of the SEM, it is important to consider that the results may exaggerate the influence of anteroposterior and vertical factors. And the palatal shape in skeletal Class III malocclusion is different from that in Class I or Class II malocclusions. This type of a palatal morphology explains that the growth of mandible does not lead to maxillary growth, which results in maxillary deficiency.

Clinically, the palatal shape in skeletal Class III malocclusion often has a great impact on treatment planning and execution. This is because application of a palatal expander or maxillary repositioning surgery could be considered in the case of a deficient maxilla. The palatal expansion leads to a change in the shape of the mid-face, which will require further treatment modification in the mandibular dentition to obtain harmonious occlusion. Since these changes result in additional changes in the maxillary and mandibular complexes, studies on the skeletal pattern and palatal morphology are needed to be further expanded.

5 | CONCLUSION

This study attempted to overcome the problems interpret the relationship between the facial skeletal pattern and the palatal shape based on SEM. For this purpose, skeletal pattern analysis of class III malocclusion and geometrical morphometric analysis of palatal morphology were performed. The transverse, vertical and anteroposterior latent variables were extracted from the skeletal pattern, and the structural equation model was constructed through the extraction of the PCs of the palatal shape. As the transverse facial skeletal width increased, palatal morphology was narrow, deep and long. Therefore, it is necessary to evaluate the morphology of the palate in consideration of transverse skeletal pattern in Class III malocclusion and reflect it to treatment planning.

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