Original Article

Classification of the Skeletal Variation in Normal Occlusion

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Abstract: The aims of this study were to classify normal occlusion samples into specific skeletal types and to analyze the dentoalveolar compensation in a normal occlusion in order to provide the clinically applicable differential diagnostic criteria for an individual malocclusion patient. Lateral cephalograms of 294 normal occlusion samples, who were selected from 15,836 adults through a community dental health survey, were measured. Using a principal component analysis, two factors representing the anteroposterior and vertical skeletal relationships were extracted from 18 skeletal variables. Cluster analysis was then used to classify the skeletal patterns into nine types. Nine types of polygonal charts with a profilogram were created. Discriminant analysis with a stepwise entry of variables was designed to identify several potential variables for skeletal typing, which could be linked with computerized cephalometric analysis for an individual malocclusion patient. Discriminant analysis assigned 87.8% classification accuracy to the predictive model. It was concluded that because the range of a normal occlusion includes quite diverse anteroposterior and vertical skeletal relationships, classifying the skeletal pattern and establishing an individual dentoalveolar treatment objective might facilitate clinical practice. (*Angle Orthod* 2005;75:303–311.)

Key Words: Skeletal typing; Principal component analysis; Cluster analysis

INTRODUCTION

It has long been emphasized that a patient with a malocclusion should not be treated by standardized cephalometric analysis, but rather by the individual norm of cephalometric analysis.[1–4] A relatively good occlusion with a skeletal discrepancy is not uncommon, and a large variation in the skeletal relationship has been reported even in normal occlusion samples.[1,2] This confirms that significant anatomical variations exist even within a so-called normal occlusion and to a greater degree in a malocclusion. Therefore, simple cephalometric analysis for a patient using the numerical standards derived from other persons with an average skeletal relationship is unreasonable.

Many studies on the dentoalveolar compensatory mechanism have been reported, and most of them have been in favor of a more individualized treatment approach according to the individual skeletal type.[5–9] However, they separately analyzed the skeletal pattern either anteroposteriorly or vertically. The terms retrognathic and prognathic are inadequate for describing the facial types.[6] The variations in the vertical dimensions are also significant when identifying facial types. Therefore, it is important to define the multidimensional combinations in order to make a more accurate identification of the facial types because the interrelation of the anteroposterior and vertical relationship is responsible for the various facial types.[4,5,10] Considering both the anteroposterior and vertical dimensions at the same time would lead to a more precise diagnosis from which a more specific treatment could be planned.

The nonnumerical, graphic evaluation of the facial form developed by Fishman,[2] cephalomorphic analysis, is believed to be a sophisticated method in tailoring an individualized clinical diagnosis and treatment plan. However, many cephalometric analyses are computer-based, printing analysis reports with a ''norm'' and ''variation.'' In this circumstance, although the visual approach to classify the skeletal type gives a direct indication, a mathematical computation corresponds to the current computer-based environment more harmoniously. In this respect, digitizing the cephalometric tracing, immediate classification of the skeletal pattern, and analysis of the dentoalveolar characteristics

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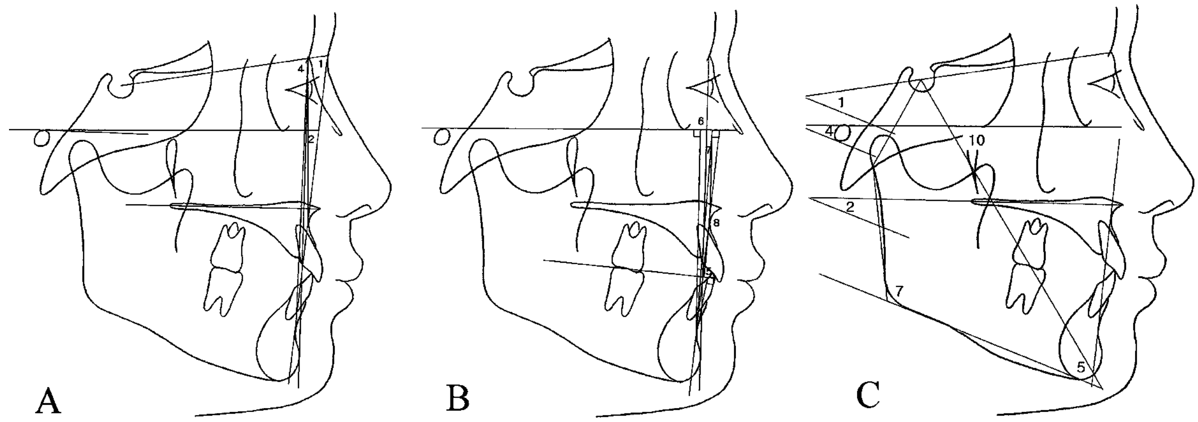


FIGURE 1. Anteroposterior (A, B) and vertical skeletal (C) measurements.

with an individualized skeletal type would be more valuable than just a simple ''standardized'' analysis.

The aim of this study was to classify normal occlusion samples into specific skeletal types with the aid of mathematics. In addition, the dentoalveolar compensation mechanism and the ranges of skeletal variations that could permit the establishment of a normal occlusion are discussed. Discriminant analysis was also designed to provide a computerized classification method for an individual malocclusion patient.

MATERIALS AND METHODS

Selection of normal occlusion samples

Two hundred ninety-four normal occlusion samples were selected from 15,836 adults through a community dental health survey in Seoul, South Korea. These subjects consisted of 177 male and 117 female individuals with a mean age of 20.2 years. The selection criteria of the normal occlusion samples were as follows:

1. Class I molar and canine relationship with normal occlusal interdigitation;
2. fully erupted permanent dentition except the third molars;
3. normal overjet and overbite (2–4 mm);
4. minimal crowding (less than three mm) and spacing (less than one mm);
5. no history of previous orthodontic or prosthodontic treatment.

Cephalometric analysis

Complete orthodontic records were made, which included various radiographs, casts, and photographs. The lateral cephalograms were traced, digitized, and analyzed by Visual C++ (Microsoft, Redmond, Wash) software that was designed for this study. The cephalometric measurements used were as follows.

Anteroposterior skeletal measurements. The anteroposterior skeletal measurements are as follows (Figure 1A,B):

1. SN-AB, the angle between the SN plane and the AB plane;
2. FH-AB, the angle between the FH plane and the AB plane;
3. APDI, the anteroposterior dysplasia indicator, the sum of the FH plane to the facial plane angle, the FH plane to the palatal plane angle, and the AB line to the facial plane angle;
4. ANB, the angle between the NA line and the NB line;
5. Wits appraisal, the distance between perpendiculars drawn from point A and point B onto an occlusal plane;
6. AF-BF, the distance between the perpendiculars drawn from point A and point B onto the Frankfort horizontal plane;
7. AFB, the angle between the AF line and the BF line;
8. AB plane angle, the angle between the AB plane and the facial plane.

Vertical skeletal measurements. The vertical skeletal measurements are as follows (Figure 1C):

1. SN-MP, the angle between the SN plane and the mandibular plane;
2. PMA, the angle between the palatal plane and the mandibular plane;
3. ODI, overbite depth indicator, the sum of the AB to the mandibular plane angle and the palatal plane angle;
4. FMA, the angle between the FH plane and the mandibular plane;
5. AB-MP, the angle between the AB line and the mandibular plane;
6. Björk sum: the sum of the saddle angle, articular angle, and gonial angle;
7. Gonial angle, the angle formed by the mandibular plane and the line drawn from the articulare to the posterior-inferior border of the ramus;
8. APFHR, the anterior-posterior facial height ratio, the

TABLE 1. Variability of Skeletal Measurements

	Minimum	Mean ± SD	Maximum	Range
FH-AB	72.7	84.6 ± 4.4	97.3	24.6
ANB	−3.0	2.6 ± 1.9	8.0	10.9
SN-AB	63.9	76.1 ± 4.7	87.4	12.0
APDI	73.7	84.3 ± 3.9	93.9	20.2
Wits appraisal	−9.0	−1.7 ± 2.6	8.6	17.5
AF-BF	−6.2	4.3 ± 3.6	14.0	20.3
AFB	−4.3	3.0 ± 2.4	9.3	13.6
ABPA	−12.2	−4.3 ± 2.6	4.7	16.9
PMA	11.7	23.6 ± 4.5	35.2	23.5
SN-MP	16.8	31.8 ± 5.2	45.3	28.4
FMA	9.0	23.3 ± 4.7	34.8	25.8
AB-MP	55.4	72.1 ± 4.3	85.3	29.8
ODI	50.9	71.8 ± 5.4	87.3	36.4
Björk sum	376.8	391.8 ± 5.2	405.3	28.4
Gonial angle	94.2	117.1 ± 5.9	135.4	41.2
AP FHR	58.7	68.8 ± 4.7	84.1	25.4
AL FHR	50.9	55.6 ± 1.7	60.2	9.3
Y axis angle	53.1	61.4 ± 2.9	70.8	17.6

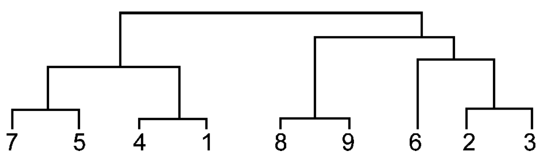


FIGURE 2. Tree dendrogram of cluster analysis derived from 294 lateral cephalograms.

ratio of the posterior facial height to the anterior facial height;

9. ALFHR, the anterior-lower facial height ratio, the ratio of the anterior lower facial height to the anterior total facial height;
10. y-axis angle, the angle between the FH plane and the S-Gn line.

Statistical analysis

Principal component analysis was used to summarize 18 skeletal variables. The factor scores were calculated for each individual, and these factor scores were then used as new variables in the following cluster analysis.

The Ward method of hierarchical cluster analysis was used to classify the skeletal pattern. The number of skeletal patterns was decided by a dendrogram.

In subgrouping the samples, the skeletal types were arranged into a contingency table with the x axis representing the anteroposterior and the y axis representing the vertical skeletal relationship. Descriptive statistics including analysis of variance and post hoc test were used to characterize the skeletal and dentoalveolar distinctions of each type. To interpret the dentoalveolar compensation mechanism, several variables indicating the position of the upper incisor, lower incisor, premolar, molar, and occlusal plane were analyzed. The correlation coefficient between the skeletal variables and the dentoalveolar variables was also calculated. Finally, discriminant analysis with stepwise entry of variables was designed to facilitate the classification of an individual malocclusion patient.

RESULTS

Initially, to test the reliability, 30 lateral cephalograms were randomly selected, which were traced and digitized again on separate days two months after the initial tracing. The error in estimation ranged from 0.00° to 0.17° and that of the linear measurements ranged from 0.00 to 0.12 mm.

Variability of skeletal relationship of normal occlusion samples

All the skeletal cephalometric measurements for normal occlusion samples showed a wide range of variation. The anteroposterior skeletal measurement FH-AB angle ranged from 72.7° to 97.3° with a mean of 84.6° (Table 1).

Classification of normal occlusion

Two factors with an eigenvalue greater than 1.0 were extracted after the principal component analysis. These two factors could account for 83.7% of the normal samples on the skeletal pattern, which were identified as the anteroposterior and vertical variables. The anteroposterior variables were mainly composed of FH-AB, ANB, SN-AB, APDI, and the Wits appraisal. The vertical variables were mainly composed of PMA, SN-MP, FMA, AB-MP, and ODI.

Figure 2 shows the tree dendrogram obtained from cluster analysis based on the two factor scores, which apparently expresses nine skeletal patterns. As an analysis of the lineage in the dendrogram, Types 7 and 5, Types 4 and 1, Types 8 and 9, and Types 2 and 3 were in close relationship with each other. Type 6 was somewhat different from the other types.

These nine types were arranged into a three × three contingency table. This table represents a skeletal Class III tendency on the right part, a skeletal Class II tendency on the left part, a hyperdivergent facial pattern on the upper part, and a hypodivergent facial pattern on the lower part. The nomenclature selected for the skeletal types was parallel to the skeletal characteristics of each facial type (Figure 3).

Pattern analysis and comparison of skeletal and dentoalveolar characteristics of the nine skeletal types

Types 1, 3, 7, and 9 represented the extremes of the characteristic skeletal pattern that could form a normal occlusion. To observe a representative case of each type, a profilogram, which was closest to the mean value of any variable of the type, was depicted. Figure 4 shows the superimposed profilograms for the cases that were presented as a prototype.

TABLE 2. Means and Standard Deviations for Skeletal Measurements of the Nine Types

	Type 1 (n = 52)	Type 2 (n = 48)	Type 3 (n = 8)	Type 4 (n = 19)
Anteroposterior skeletal measurements				
FH-AB	80.8 ± 2.5	84.7 ± 2.1	90.8 ± 2.0	77.6 ± 1.9
ANB	4.2 ± 2.1	2.5 ± 1.2	−0.8 ± 1.4	5.0 ± 1.0
APDI	81.1 ± 2.7	83.7 ± 2.2	90.1 ± 1.7	78.6 ± 2.2
SN-AB	72.0 ± 2.4	75.2 ± 2.2	82.1 ± 2.1	68.3 ± 2.0
Wits appraisal	−0.8 ± 1.7	−2.8 ± 1.8	−7.3 ± 1.2	1.2 ± 2.0
AF-BF	7.6 ± 2.1	4.3 ± 1.8	−0.7 ± 1.7	9.9 ± 1.8
AFB	5.2 ± 1.4	3.0 ± 1.2	−0.5 ± 1.2	6.8 ± 0.9
ABPA	−6.0 ± 1.6	−3.6 ± 1.5	1.0 ± 2.1	−7.9 ± 1.5
Vertical skeletal measurements				
PMA	27.0 ± 2.9	28.4 ± 2.6	27.5 ± 3.1	25.0 ± 2.7
SN-MP	36.1 ± 3.1	36.9 ± 2.5	35.5 ± 3.5	35.3 ± 2.8
FMA	27.3 ± 3.1	27.5 ± 2.5	26.7 ± 1.6	26.0 ± 2.7
AB-MP	71.9 ± 1.6	67.9 ± 1.8	62.4 ± 3.0	76.5 ± 1.6
ODI	72.1 ± 2.8	66.9 ± 3.0	61.6 ± 4.5	77.4 ± 3.5
Björk sum	396.1 ± 3.1	396.9 ± 2.5	395.5 ± 3.5	395.3 ± 2.8
Gonial angle	120.4 ± 5.0	121.2 ± 3.9	121.9 ± 5.8	117.2 ± 3.9
AP FHR	65.7 ± 2.7	63.8 ± 2.4	65.3 ± 2.9	66.2 ± 2.2
AL FHR	55.8 ± 1.5	55.9 ± 1.6	56.9 ± 1.7	54.5 ± 1.3
Y-axis angle	63.7 ± 2.5	61.9 ± 2.5	61.5 ± 1.1	64.1 ± 2.5

The skeletal variables and several dentoalveolar measurements with the means and standard deviations for the nine different types were analyzed (Tables 2 and 3). Because there were nine dependent variables for each pairwise test, it was difficult to observe a regular sequence among these types. Therefore, correlation analysis provided a clearer and continuous insight into the relationship between the skeletal variables and the dentoalveolar measurements. A strong positive correlation was found between the anteroposterior relationship of the mandible and the inclination of the upper and lower incisors. The angulation of the upper premolar and molar showed a negative correlation with the PMA. On the other hand, the angulation of the lower premolar and molar showed a positive correlation

TABLE 3. Means and Standard Deviations for Dentoalveolar Measurements

	Type 1	Type 2	Type 3	Type 4
Upper and lower incisor				
U1 to SN	102.7 ± 4.7	104.1 ± 5.6	107.0 ± 2.8	98.8 ± 4.0
U1 to FH	111.5 ± 4.6	113.5 ± 4.9	115.7 ± 4.1	108.1 ± 3.0
U1 to PP	111.7 ± 4.8	112.6 ± 4.9	115.0 ± 4.0	109.0 ± 4.5
L1 to SN	47.8 ± 4.6	51.7 ± 4.7	58.6 ± 4.9	44.7 ± 4.2
L1 to FH	56.5 ± 4.6	61.2 ± 5.4	67.4 ± 4.0	54.0 ± 4.2
L1 to NB	30.2 ± 4.2	27.0 ± 5.2	22.5 ± 3.5	31.2 ± 3.9
L1 to MP	96.1 ± 4.3	91.4 ± 4.5	85.9 ± 4.3	100.1 ± 4.4
Interincisal angle	125.1 ± 7.1	127.6 ± 8.7	131.6 ± 6.1	125.9 ± 5.3
Premolar and molar				
U4 to PP	88.5 ± 3.2	89.4 ± 3.5	92.0 ± 3.8	88.3 ± 4.3
U5 to PP	85.3 ± 4.0	85.6 ± 3.9	87.3 ± 5.1	84.3 ± 2.9
U6 to PP	80.6 ± 4.5	81.2 ± 4.8	81.9 ± 5.3	79.4 ± 4.5
U7 to PP	73.2 ± 6.3	72.9 ± 6.7	74.3 ± 5.4	71.5 ± 6.6
L4 to MP	82.7 ± 4.4	80.1 ± 4.3	79.6 ± 4.1	85.0 ± 3.3
L5 to MP	81.4 ± 4.0	79.5 ± 3.6	77.3 ± 4.4	83.2 ± 3.6
L6 to MP	79.8 ± 4.0	78.2 ± 3.3	78.5 ± 4.4	82.4 ± 3.2
L7 to MP	83.7 ± 5.2	83.1 ± 3.9	83.7 ± 4.1	86.4 ± 3.7
Occlusal plane				
SN-OP	19.0 ± 3.0	18.2 ± 3.1	16.9 ± 2.9	20.2 ± 3.2
FH-OP	10.2 ± 3.0	8.8 ± 2.8	8.1 ± 2.0	10.9 ± 3.5
PP-OP	9.9 ± 2.8	9.7 ± 2.8	8.9 ± 1.7	9.9 ± 2.3
MP-OP	17.1 ± 2.9	18.7 ± 2.5	18.7 ± 3.2	15.0 ± 2.2
AB-OP	91.0 ± 2.1	93.5 ± 2.2	98.9 ± 1.3	88.5 ± 2.5

TABLE 2. Extended

Type 5 (n = 41)	Type 6 (n = 75)	Type 7 (n = 7)	Type 8 (n = 26)	Type 9 (n = 18)
82.8 ± 2.1	87.9 ± 2.6	77.5 ± 2.8	86.2 ± 1.8	91.2 ± 2.8
3.5 ± 1.1	1.3 ± 1.2	6.0 ± 1.4	2.1 ± 1.1	0.2 ± 0.9
83.2 ± 2.1	87.3 ± 2.6	79.2 ± 3.2	85.9 ± 2.4	88.9 ± 2.7
74.3 ± 2.1	79.8 ± 2.9	70.8 ± 3.5	79.1 ± 2.1	82.7 ± 2.6
−0.2 ± 1.6	−3.1 ± 1.9	4.2 ± 2.4	−1.0 ± 2.3	−3.2 ± 1.7
5.7 ± 1.6	1.7 ± 2.1	10.0 ± 2.6	3.1 ± 1.5	−1.0 ± 2.3
4.0 ± 1.1	1.2 ± 1.5	6.8 ± 1.6	2.1 ± 1.0	−0.7 ± 1.6
−5.8 ± 1.7	−2.6 ± 1.7	−9.7 ± 1.4	−4.1 ± 1.6	−1.4 ± 1.4
21.4 ± 1.8	22.9 ± 2.3	17.8 ± 3.2	16.5 ± 2.9	17.7 ± 2.2
30.3 ± 2.5	30.4 ± 2.5	26.2 ± 3.3	23.3 ± 2.9	24.0 ± 1.5
21.8 ± 2.6	22.3 ± 2.1	19.6 ± 3.4	16.2 ± 2.8	15.4 ± 2.8
75.4 ± 1.9	69.8 ± 2.0	83.0 ± 1.5	77.6 ± 2.4	73.4 ± 1.4
75.8 ± 3.0	69.2 ± 3.5	84.7 ± 2.0	77.3 ± 3.2	71.1 ± 2.9
390.3 ± 2.5	390.4 ± 2.5	386.2 ± 3.3	383.3 ± 2.9	384.0 ± 2.5
115.4 ± 4.8	117.1 ± 4.6	111.8 ± 5.5	110.6 ± 5.3	110.5 ± 5.6
70.3 ± 2.6	69.6 ± 2.5	73.8 ± 3.3	76.5 ± 3.0	75.4 ± 2.4
55.1 ± 2.0	55.7 ± 1.7	53.9 ± 1.4	55.5 ± 1.3	56.0 ± 1.6
61.6 ± 1.8	60.3 ± 2.2	62.2 ± 1.7	59.7 ± 2.2	57.7 ± 2.9

with the AB-MP angle. The occlusal plane angle correlated with the anteroposterior skeletal relationship with a more flattened occlusal plane for the Class III patterns. However, the interincisal angle did not show substantively significant correlation with the anteroposterior and vertical skeletal variables (Table 4).

Stepwise variable selection and discriminant analysis to determine each skeletal typing

The stepwise variable selection generated a four-variable model (AB-MP, SN-AB, PMA, and ANB) that produced the most efficient separation between the nine types. Be-

TABLE 3. Extended

Type 5	Type 6	Type 7	Type 8	Type 9
104.4 ± 4.9	107.8 ± 5.5	101.2 ± 4.3	108.9 ± 5.3	108.4 ± 4.8
112.9 ± 5.1	115.9 ± 5.2	107.9 ± 2.4	116.0 ± 5.6	116.9 ± 6.1
113.3 ± 4.8	115.3 ± 4.7	109.6 ± 3.7	115.7 ± 5.9	114.6 ± 6.5
50.5 ± 5.5	56.5 ± 5.0	50.5 ± 4.8	56.1 ± 5.5	61.9 ± 6.3
59.0 ± 5.3	64.6 ± 4.9	57.2 ± 5.5	63.2 ± 5.1	70.5 ± 5.9
29.1 ± 4.7	25.2 ± 4.6	29.4 ± 4.8	26.2 ± 5.2	21.1 ± 4.6
99.2 ± 5.4	93.1 ± 4.6	103.3 ± 3.1	100.6 ± 5.5	94.1 ± 4.6
126.1 ± 8.5	128.7 ± 7.6	129.3 ± 6.7	127.2 ± 9.3	133.6 ± 8.7
91.1 ± 3.9	91.5 ± 3.6	91.7 ± 2.9	93.1 ± 3.9	93.0 ± 4.0
87.3 ± 4.1	88.7 ± 3.6	88.6 ± 3.1	89.2 ± 4.5	89.6 ± 3.8
83.2 ± 4.6	84.6 ± 3.6	85.0 ± 4.4	86.5 ± 4.8	84.6 ± 4.4
76.4 ± 6.0	77.2 ± 5.8	78.2 ± 5.1	79.8 ± 6.6	78.4 ± 6.9
85.5 ± 4.2	81.7 ± 3.7	88.0 ± 2.7	88.8 ± 3.8	85.1 ± 3.7
84.3 ± 3.8	81.1 ± 4.1	86.7 ± 1.9	87.3 ± 3.5	84.5 ± 3.2
82.9 ± 3.5	80.6 ± 3.9	84.0 ± 2.5	86.2 ± 4.6	83.6 ± 3.8
87.0 ± 4.9	84.5 ± 4.5	88.8 ± 2.5	88.8 ± 5.2	89.4 ± 4.4
15.9 ± 3.1	14.1 ± 3.2	14.0 ± 3.1	12.1 ± 3.1	11.4 ± 4.2
7.4 ± 2.9	6.0 ± 3.0	7.3 ± 0.9	5.0 ± 2.9	2.9 ± 4.0
7.0 ± 2.9	6.6 ± 2.4	5.6 ± 2.4	5.3 ± 2.4	5.2 ± 3.5
14.4 ± 2.7	16.3 ± 2.6	12.2 ± 3.2	11.2 ± 3.4	12.5 ± 2.7
90.2 ± 2.1	93.9 ± 2.3	84.8 ± 2.8	91.2 ± 2.9	94.1 ± 2.2

TABLE 4. Correlation Coefficient Between Several Skeletal Variables and Dentoalveolar Measurements

	SN-AB	ANB	PMA	AB-MP
Upper and lower incisor				
U1 to SN	.615**	−.318**	−.164**	−.173**
U1 to FH	.479**	−.358**	−.119*	−.241**
U1 to PP	.328**	−.264**	−.259**	−.195**
L1 to SN	.756**	−.551**	−.310**	−.178**
L1 to FH	.638**	−.588**	−.274**	−.234**
L1 to NB	−.455**	.583**	.195**	.192**
L1 to MP	−.300**	.390**	−.346**	.674**
Interincisal angle	.189**	−.230**	−.140**	−.025 NS
Premolar and molar				
U4 to PP	.279**	−.229**	−.519**	.065 NS
U5 to PP	.302**	−.232**	−.473**	.031 NS
U6 to PP	.314**	−.194**	−.469**	.082 NS
U7 to PP	.265**	−.108 NS	−.403**	.135*
L4 to MP	−.084 NS	.137*	−.490**	.612**
L5 to MP	−.033 NS	.121*	−.518**	.598**
L6 to MP	.052 NS	.032 NS	−.531**	.539**
L7 to MP	.035 NS	−.029 NS	−.403**	.425**
Occlusal plane				
SN-OP	−.733**	.304**	.390**	−.106 NS
FH-OP	−.575**	.378**	.359**	−.030 NS
PP-OP	−.380**	.255**	.636**	−.127*

* $P < .05$; ** $P < .01$; NS, not significant.

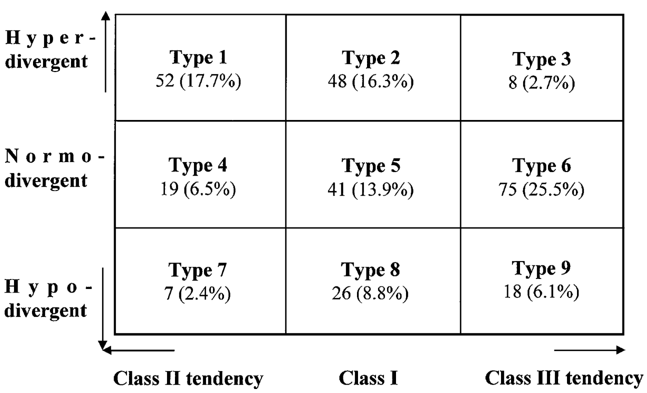


FIGURE 3. Classification diagram with frequency of each skeletal type.

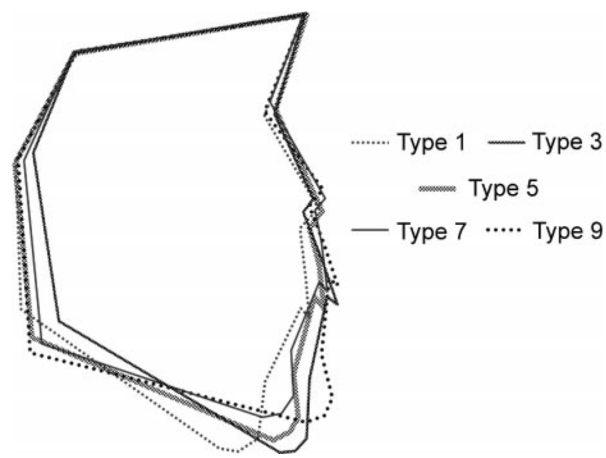


FIGURE 4. The superimposition of profilogram was done by superimposing on the SN plane and registering on the Sella.

cause Wilks lambda was used as the entry criterion, the variables that produced the smallest lambda for each step were selected.

There were four functions with nonzero eigenvalues. In particular, the first and second eigenvalues were more than 100 times larger than the eigenvalue for the third and fourth function, and only the first two functions were found to be significant. A higher canonical correlation coefficient was found for the first two functions, which indicated that there is a strong relationship between the types and the first two discriminant functions.

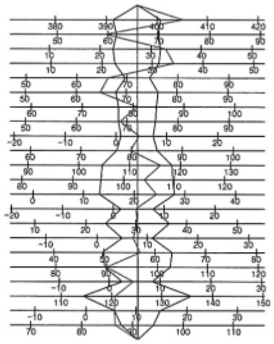
The standardized canonical discriminant function coefficient showed that the AB-MP (0.858) and SN-AB (0.714) exerted the highest contribution on the function 1 and 2, respectively. Fisher linear combination of the discriminating variables, which maximizes the group differences while minimizing the variation within the groups, was calculated for the computerized classification algorithm. The sum of the correct predictions resulted in an 87.8% accuracy.

DISCUSSION

The results confirmed that there was a wide range of normal variations not only in the skeletal relationship but also in the dentoalveolar compensation within the normal occlusion samples. It was interesting that the skeletal patterns of the normal occlusion samples were similar to those of the malocclusion patients with skeletal imbalances. In-

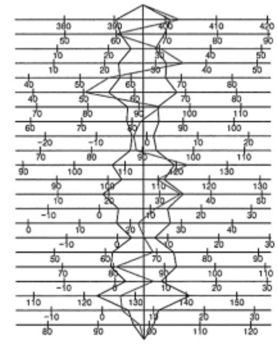
Type 1

Measure Name	Mean	S.D.	Data1
Bjork sum	396.1	3.1	405.2
APFHR	65.7	2.7	59.4
FMA	27.3	3.1	33.0
PMA	27.0	2.9	34.2
AB-MP	71.9	1.6	66.1
ODI	72.1	2.8	64.9
FH-AB	80.8	2.5	80.9
SN-AB	72.0	2.4	68.7
ANB	4.2	2.1	4.6
APDI	81.1	2.7	79.7
U1 to FH	111.5	4.6	116.2
U1 to SN	102.7	4.7	104.0
U1 to NA	20.6	4.9	24.4
U1 to NA (mm)	4.7	2.1	4.5
L1 to NB	30.2	4.2	30.3
L1 to NB (mm)	8.0	2.0	7.3
FMIA	56.5	4.6	57.0
IMPA	96.1	4.3	90.0
L1 to A-Pog (mm)	5.5	2.0	4.8
U1 to L1	125.1	7.1	120.8
FH-OP	10.2	3.0	5.7
AB-OP	91.0	2.1	86.6



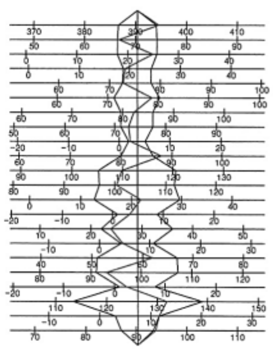
Type 3

Measure Name	Mean	S.D.	Data1
Bjork sum	395.5	3.5	402.7
APFHR	65.3	2.9	59.9
FMA	26.7	1.6	30.1
PMA	27.5	3.1	35.5
AB-MP	62.4	3.0	55.6
ODI	61.6	4.5	50.3
FH-AB	90.8	2.0	94.2
SN-AB	82.1	2.1	81.7
ANB	−0.8	1.4	−2.6
APDI	90.1	1.7	88.8
U1 to FH	113.5	4.1	122.3
U1 to SN	107.0	2.8	109.8
U1 to NA	26.7	5.3	34.1
U1 to NA (mm)	8.6	3.2	11.0
L1 to NB	22.5	3.5	21.5
L1 to NB (mm)	5.1	1.5	5.3
FMIA	67.4	4.0	69.3
IMPA	85.9	4.3	80.6
L1 to A-Pog (mm)	5.6	2.3	7.6
U1 to L1	131.6	6.1	127.0
FH-OP	8.1	2.0	3.9
AB-OP	98.9	1.3	98.1



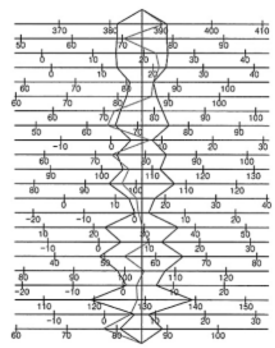
Type 5

Measure Name	Mean	S.D.	Data1
Bjork sum	390.3	2.5	394.6
APFHR	70.3	2.6	66.8
FMA	21.8	2.6	25.0
PMA	21.4	1.8	19.1
AB-MP	75.4	1.9	72.8
ODI	75.8	3.0	78.7
FH-AB	82.8	2.1	82.2
SN-AB	74.3	2.1	72.6
ANB	3.5	1.1	2.2
APDI	83.2	2.1	88.0
U1 to FH	112.9	5.1	109.9
U1 to SN	104.4	4.9	100.4
U1 to NA	21.2	5.6	22.0
U1 to NA (mm)	4.8	2.6	3.4
L1 to NB	29.1	4.7	23.9
L1 to NB (mm)	7.5	2.1	4.6
FMIA	59.0	5.3	61.9
IMPA	99.2	5.4	93.1
L1 to A-Pog (mm)	4.5	2.3	2.4
U1 to L1	126.1	8.5	132.0
FH-OP	7.4	2.9	11.7
AB-OP	90.2	2.1	93.9



Type 7

Measure Name	Mean	S.D.	Data1
Bjork sum	386.2	3.3	390.5
APFHR	73.8	3.3	70.3
FMA	19.6	3.4	22.4
PMA	17.8	3.2	21.2
AB-MP	83.0	1.5	85.4
ODI	84.7	2.0	86.6
FH-AB	77.5	2.8	72.1
SN-AB	70.8	3.5	64.1
ANB	6.0	1.4	7.5
APDI	79.2	3.2	73.3
U1 to FH	107.9	2.4	105.4
U1 to SN	101.2	4.3	97.3
U1 to NA	15.3	1.7	14.3
U1 to NA (mm)	1.4	0.9	0.7
L1 to NB	29.4	4.8	29.7
L1 to NB (mm)	8.5	2.7	10.0
FMIA	57.2	5.5	53.8
IMPA	103.3	3.1	103.8
L1 to A-Pog (mm)	3.6	2.0	2.7
U1 to L1	129.3	6.7	128.5
FH-OP	7.3	0.9	5.2
AB-OP	84.8	2.8	77.4



Type 9

Measure Name	Mean	S.D.	Data1
Bjork sum	384.0	2.5	382.4
APFHR	75.4	2.4	76.1
FMA	15.4	2.8	10.4
PMA	17.7	2.2	15.1
AB-MP	73.4	1.4	72.3
ODI	71.1	2.9	67.9
FH-AB	91.2	2.8	97.1
SN-AB	82.7	2.6	85.4
ANB	0.2	0.9	−0.8
APDI	88.9	2.7	92.4
U1 to FH	116.9	6.1	125.1
U1 to SN	108.4	4.8	113.4
U1 to NA	25.1	5.8	29.9
U1 to NA (mm)	6.5	2.4	7.6
L1 to NB	21.1	4.6	22.0
L1 to NB (mm)	3.8	1.8	4.2
FMIA	70.5	5.9	74.0
IMPA	94.1	4.6	95.6
L1 to A-Pog (mm)	2.8	2.0	3.6
U1 to L1	133.6	8.7	128.9
FH-OP	2.9	4.0	−6.0
AB-OP	94.1	2.2	91.1

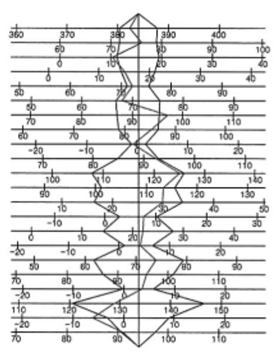


FIGURE 5. Polygonal charts that were produced by computerized cephalometric analysis combined with nine skeletal typings.

deed, this study was inspired by the research of Casko and Sheperd.[1] They reported that a naturally occurring ANB angle ranged from −3.0 to 8.0, which was identical to our data. Table 1, as compared with the that of Casko and Sheperd,[1] showed a broader range in the skeletal variables, whereas it showed a less diverse range in the dentoalveolar measurements.

As a result of the principal component analysis, although the ODI and AB-MP have been regarded as the vertical skeletal variables, they also are estimated to have an anteroposterior component. This was inferred from the fact that the factor loading of the ODI was higher in anteroposterior factor than in vertical factor. Consequently, the ODI decreased according to the anteroposterior relationship in the same vertical skeletal pattern. These findings are consistent with the report by Yang et al,[11] where the ODI decreased with increases in the APDI in a normal overbite sample, which reflects the characteristics of the AB-MP.

The Class I skeletal pattern and the normodivergent pattern were the most frequent skeletal patterns among the three types of anteroposterior and vertical skeletal relationships. However, Type 6 had the largest number of members. Unlike Caucasians, there is a higher prevalence (more than 20%) of Class III malocclusion in Asians.[12] Therefore, it appears that our society will more easily accept the Class III tendency with normodivergent skeletal pattern as ‘‘normal,’’ although it is difficult to generalize. Types 3 and 7 were the least dominant types among the normal occlusion samples. On the other hand, it is known to be the predominant type in the malocclusion group.[13] This suggests that a Class III hyperdivergent pattern and a Class II hypodivergent pattern are difficult to constitute a normal occlusion.

The results of this study and the studies of the earlier authors[1,14–16] suggest that a proclined upper incisor was correlated with a forward mandibular position and a retroclined upper incisor with a backward mandibular position. A vertical skeletal pattern also correlated with the more retroclined incisors to form a normal occlusion, which is a well-known phenomenon of the dentoalveolar compensatory mechanism. However, the interincisal angle showed a relatively narrow range and a poor correlation with the anteroposterior or vertical skeletal variables. Therefore, the relatively inert feature of the interincisal angle suggested the importance of the incisal relationship to form a normal occlusion with an esthetic facial profile.

Both the anteroposterior and vertical positions of the mandible influenced the upper premolar and molar axes to the palatal plane angle. The lower premolar and molar axes to the mandibular plane angle were mainly influenced by the vertical mandibular position. This observation pertains to the research reported by Chang and Moon,[17] who reported the relationship between the tooth axis and the vertical skeletal pattern. The variation in the occlusal plane angle was also notable, with the Class II patterns showing a steep occlusal plane and a Class III pattern showing a flat occlusal plane. This result is similar to the finding of Simons[18] that a Class II molar relationship changes into a Class I molar relationship as the occlusal plane rotates downward-backward and the report of Jacobson[19] that a Class III changes into a Class I as the occlusal plane rotates upward-forward.

The main advantage of discriminant analysis was the compatibility with computerized cephalometrics. The polygonal chart for each skeletal type, which is composed of several skeletal and dentoalveolar measurements, could be created using Excel VBA (Microsoft) (Figure 5) that is linked to the classification algorithm. Therefore, it is possible to classify the individual malocclusion patients immediately after digitizing their cephalograms automatically. Initially, this computerized approach needs a mathematical computation of the cephalometric variables. On a clinical basis, inclusion of fewer variables in the discriminant analysis results in a greater possibility of application. By reducing the cephalometric variables and incorporating them into a discriminating computation, this study attempted to identify a more prospective method to distinguish the specific skeletal type from an individual skeletal pattern.

The contribution of the individual variables to the discriminant function could be explained by the standardized canonical discriminant function coefficients. However, the similarity between a single variable and a discriminant function, namely, the structure coefficient, showed that function 1 is closely related to AB-MP (0.975). The Björk sum (0.744) was the most dominant variable on function 2. Therefore, function 1 could refer to the ODI dimension if the contribution of palatal plane angle is small. Function 2 could be called the Björk sum dimension. Therefore, the most similar variables to the statistically significant two discriminant functions determine the skeletal morphology in terms of a quadrangle, which is composed of four angular points, Sella, Gonion, and two points of contact formed by the SN-AB and AB-MP.

The proportion of cases correctly classified indicates the accuracy of this procedure and indirectly confirms the degree of group separation. Because there were nine types in this study, the prior probability for these nine groups was only 11.1%. Therefore, the hit ratio of 87.8% is a considerable improvement, although it is far from perfect. More favorably, there were no misclassified cases in Types 1, 3, 7, and 9, which represent the skeletal extremes.

The skeletal patterns are the relationships that we have very little control of in orthodontic treatment except by the use of surgical techniques. A differential diagnosis is often difficult in these cases that fall on the borderline between a nonsurgical orthodontic correction and a surgical orthodontic treatment modality. Therefore, the ranges in skeletal variation will provide an additional basis for the skeletal relationships that can allow normal occlusions by a dental adjustment.

Although this study investigated the dentoalveolar compensation according to the anteroposterior and vertical skeletal relationships, more studies aimed at evaluating the transverse skeletal relationship in the three-dimensional plane are recommended. In addition, it will be necessary to increase the number of samples and examine the sex differences to establish the concrete limitations of dentoalveolar compensation as well as the appropriate diagnostic criteria for individual craniofacial relationship.

CONCLUSIONS

An assessment of the individual skeletal variability using the mean cephalometric measurements is unreasonable because there is a wide range of normal variations in the skeletal relationship that can form a normal occlusion. The individual treatment goal for each specific skeletal type can be established if the characteristics of dentoalveolar compensation of the extreme skeletal types are carefully studied and the dentoalveolar measurements are examined. In this aspect, a skeletal type classification linked with computerized cephalometric analysis will be useful in clinical practice.

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