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Analysis of dentoalveolar compensation and discrimination of skeletal types

Ji-Young Kim1), Tae-Woo Kim2), Dong-Seok Nahm3), Young-Il Chang4)

The purpose of this study is to analyze dentoalveolar compensation in normal occlusion samples previously classified into 9 skeletal types, and to provide clinically applicable diagnostic criteria for individual malocclusion patients. Cephalometric measurements of the 294 normal occlusion samples previously divided into 9 types were analyzed. The descriptive features of dentoalveolar variables were compared for the 9 types using analysis of variance, followed by *post hoc* multiple comparisons. In addition, the correlation between skeletal and dentoalveolar variables were analyzed. Discriminant analysis with a stepwise entry of variables was designed to find out several potential variables for use in skeletal typing. The dentoalveolar compensation pattern of the skeletal types varied, especially with regards to the variables that indicated the inclination of incisors and the occlusal plane. Stepwise variable selection identified four variables: AB- MP, SN-AB, PMA and ANB. Discriminant analysis assigned a classification accuracy of 87.8% to the predictive model. On the basis of these results, this study could provide rudimentary information for the development of diagnostic criteria and treatment guidelines for individual skeletal types.

Key words : Skeletal Type, Dentoalveolar Compensation, Discriminant Analysis

In the field of orthodontics, it has long been emphasized that treatment goals should be tailored to the individual patient. Relatively large variations in the skeletal relationship have been reported even in normal occlusion samples.[1-3] This is caused by individual variations in the degree and the direction of jaw growth. In addition, the development of the upper and lower jaws is not always coordinated. Therefore, there is a need for a mechanism to coordinate the growth and position of the teeth relative to their jaw bases in order to achieve and maintain a normal relationship between the upper and lower dental arches. Solow[4] termed this mechanism as the dentoalveolar compensatory mechanism, and defined it as a mechanism by which the development of the dental and alveolar arches is controlled in order to assure the occlusion of the teeth and their adaptation to the basal parts of the jaws. A great deal of research has been done regarding the dentoalveolar compensatory mechanism, with most of it

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1) Former graduate student, 2) Chairman, Associate Professor, 3) Professor, 4) Professor, Department of Orthodontics, College of Dentistry, Seoul National University

Reprint requests to : **Young-Il Chang**
28-2 Yoenkun-dong, Chongno-ku, Seoul 110-749, Korea
Department of Orthodontics, College of Dentistry, Seoul National university.
82-2-760-2600 / dmajor@empal.com

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Table 1. Distribution and relative frequency of each type membership N(%).

	Class II tendency	Class I	Class III tendency
Hyper-divergent	Type 1	Type 2	Type 3
	52 (17.7%)	48 (16.3%)	8 (2.7%)
Normo-divergent	Type 4	Type 5	Type 6
	19 (6.5%)	41 (19.3%)	75 (25.5%)
Hypo-divergent	Type 7	Type 8	Type 9
	7 (2.4%)	26 (8.8%)	18 (6.1%)

in favor of a more individualized treatment approach that is based on individual skeletal patterns.[5-7] Many papers have been published regarding Korean samples, including studies of dentoalveolar compensation according to skeletal patterns of normal occlusion.[2,8] Previous papers investigated dentoalveolar compensatory mechanism according to skeletal patterns that were divided on the basis of anteroposterior or vertical dimensions. However, the classification model used by Kim[1] was based on a mathematical and thus more scientific methodology, as opposed to the more subjective criteria used by other researchers. It revealed a wide range of normal variations in skeletal relationships within normal occlusion samples. Considering both anteroposterior and vertical dimensions together, the skeletal patterns were classified into nine types. Classifying the nine skeletal types through principal component analysis and hierarchical cluster analysis proved easy to interpret, as this concept referred to the topographic nomination (Table 1). Discussion of the nine skeletal types has been previously presented in Part I of this series.[1]

On the basis of the previous study, this article will discuss dentoalveolar compensation in normal occlusion samples. Discriminant analysis with a stepwise entry of variable selection was used to provide clinically applicable diagnostic criteria for individual malocclusion patients. Discriminant analysis is a statistical technique that allows the researcher to study the differences between two or more groups of objects with respect to several variables simultaneously. By reducing cephalometric variables and introducing the discriminate analysis, this study aimed at a more practical and productive method to distinguish the specific skeletal type of the individual skeletal pattern. Thus, classifying skeletal pattern and establishing individual dentoalveolar treatment objectives could provide rudimentary information to develop new diagnostic criteria and treatment guidelines for the malocclusion of individual skeletal types.

MATERIALS AND METHODS

The samples and the nine skeletal types

The identical data sets of the previous study,[1] 294 normal occlusion subjects consisted of 177 males and 117 females were analyzed. Definitions of each skeletal type, previously classified into nine skeletal types, are described as follows(Table 1).

Type 1: hyper-divergent, Class II tendency
Type 2: hyper-divergent, Class I
Type 3: hyper-divergent, Class III tendency
Type 4: normo-divergent, Class II tendency
Type 5: normo-divergent, Class I
Type 6: normo-divergent, Class III tendency
Type 7: hypo-divergent, Class II tendency
Type 8: hypo-divergent, Class I
Type 9: hypo-divergent, Class III tendency

Comparison of dentoalveolar measurements between the nine skeletal types

The definitions of the cephalometric landmarks and measurements used were previously described by Ku[2] and Kim.[1] Several variables indicating the position of the upper incisor, the lower incisor, the premolar, the molar, and the occlusal plane were analyzed to compare the differences among the types by means of a one-way analysis of variance, followed by *post hoc* Duncan's multiple range comparison tests.

Correlation coefficients between the skeletal variables (AB- MP, SN-AB, PMA and ANB) and dentoalveolar variables were also calculated. The four skeletal variables were those revealed as the important variables by means the discriminant analysis.

Stepwise variable selection and discriminant analysis to determine skeletal typing

In the clinical setting, the fewer the variables included in the discriminate analysis, the greater the possibility of practical application. The purpose of stepwise selection was to locate a more limited subset of variables that could discriminate as well as, if not better than the full set. In this study, the Wilks' lambda was used as the entry criterion. The Wilks' lambda is the ratio of the within-group sum of the squares divided by the total sum of the squares. Wilks' lambda is a statistic that takes into consideration both the differences between groups and the cohesiveness or homogeneity within groups. Since cohesiveness is the degree to which cases cluster near their group centroid, a variable which increases cohesiveness without changing the separation between the centroids may be selected over a variable which increases separation without changing the cohesiveness.[9,10] Because Wilks' lambda is an inverse statistic, we selected the variable which produced the smallest lambda for the step given. As a result of stepwise inclusion, four variables were selected. The reduced four variables were treated with discriminant analysis, which resulted in a classification function. Finally, the accuracy of the classification efficiency of the selected variables was obtained using the nine-by-nine cross table.

RESULTS

Comparison of dentoalveolar measurements among the nine skeletal types

Descriptive statistics and significance notation from the analysis of variance for dentoalveolar measurements for the nine skeletal types are listed in Table 2-1. Significant differences among all types were found. Using *post hoc* Duncan's multiple range test showed homogeneous subsets with statistically significant differences ($p < 0.05$), where a sign of inequality indicates the borderline between homogeneous subsets (Table 2-2). Because there were nine dependent variables for each pair-wise test, it was somewhat confounding to observe a regular sequence among those types. Therefore, correlation analysis was used to provide a more clear and continuous understanding of the relationship between the skeletal variables and dentoalveolar measurements (Table 3). A strong positive correlation was found between the anteroposterior relationship of the mandible and the inclination of the upper and lower incisors (SN-AB - U1 to SN 0.615; SN-AB L1 to SN 0.756). The angulation of the upper premolar and the molar showed a negative correlation with PMA. On the other hand, the angulation of the lower premolar and the molar showed a positive correlation with AB-MP angle. The occlusal plane angle was significantly correlated to the anteroposterior skeletal relationship, with a more flattened occlusal plane for Class III patterns. However, the inter-incisal angle didn't show any substantive and statistically significant correlation with the anteropo-sterior and vertical skeletal variables (Table 3).

Stepwise variable selection and discrimi-nate analysis to determine each skeletal type

Stepwise variable selection generated a four-

Table 2-1. Type means and standard deviations for dentoalveolar measurements: upper incisor

	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9	*p*
Upper and Lower Incisor										
U1 to SN	102.7 ± 4.7	104.1 ± 5.6	107.0 ± 2.8	98.8 ± 4.0	104.4 ± 4.9	107.8 ± 5.5	101.2 ± 4.3	108.9 ± 5.3	108.4 ± 4.8	**
U1 to FH	111.5 ± 4.6	113.5 ± 4.9	115.7 ± 4.1	108.1 ± 3.0	112.9 ± 5.1	115.9 ± 5.2	107.9 ± 2.4	116.0 ± 5.6	116.9 ± 6.1	**
U1 to PP	111.7 ± 4.8	112.6 ± 4.9	115.0 ± 4.0	109.0 ± 4.5	113.3 ± 4.8	115.3 ± 4.7	109.6 ± 3.7	115.7 ± 5.9	114.6 ± 6.5	**
L1 to SN	47.8 ± 4.6	51.7 ± 4.7	58.6 ± 4.9	44.7 ± 4.2	50.5 ± 5.5	56.5 ± 5.0	50.5 ± 4.8	56.1 ± 5.5	61.9 ± 6.3	**
L1 to FH	56.5 ± 4.6	61.2 ± 5.4	67.4 ± 4.0	54.0 ± 4.2	59.0 ± 5.3	64.6 ± 4.9	57.2 ± 5.5	63.2 ± 5.1	70.5 ± 5.9	**
L1 to NB	30.2 ± 4.2	27.0 ± 5.2	22.5 ± 3.5	31.2 ± 3.9	29.1 ± 4.7	25.2 ± 4.6	29.4 ± 4.8	26.2 ± 5.2	21.1 ± 4.6	**
L1 to MP	96.1 ± 4.3	91.4 ± 4.5	85.9 ± 4.3	100.1 ± 4.4	99.2 ± 5.4	93.1 ± 4.6	103.3 ± 3.1	100.6 ± 5.5	94.1 ± 4.6	**
Inter-incisal angle	125.1 ± 7.1	127.6 ± 8.7	131.6 ± 6.1	125.9 ± 5.3	126.1 ± 8.5	128.7 ± 7.6	129.3 ± 6.7	127.2 ± 9.3	133.6 ± 8.7	**
Premolar and Molar										
U4 to PP	88.5 ± 3.2	89.4 ± 3.5	92.0 ± 3.8	88.3 ± 4.3	91.1 ± 3.9	91.5 ± 3.6	91.7 ± 2.9	93.1 ± 3.9	93.0 ± 4.0	**
U5 to PP	85.3 ± 4.0	85.6 ± 3.9	87.3 ± 5.1	84.3 ± 2.9	87.3 ± 4.1	88.7 ± 3.6	88.6 ± 3.1	89.2 ± 4.5	89.6 ± 3.8	**
U6 to PP	80.6 ± 4.5	81.2 ± 4.8	81.9 ± 5.3	79.4 ± 4.5	83.2 ± 4.6	84.6 ± 3.6	85.0 ± 4.4	86.5 ± 4.8	84.6 ± 4.4	**
U7 to PP	73.2 ± 6.3	72.9 ± 6.7	74.3 ± 5.4	71.5 ± 6.6	76.4 ± 6.0	77.2 ± 5.8	78.2 ± 5.1	79.8 ± 6.6	78.4 ± 6.9	**
L4 to MP	82.7 ± 4.4	80.1 ± 4.3	79.6 ± 4.1	85.0 ± 3.3	85.5 ± 4.2	81.7 ± 3.7	88.0 ± 2.7	88.8 ± 3.8	85.1 ± 3.7	**
L5 to MP	81.4 ± 4.0	79.5 ± 3.6	77.3 ± 4.4	83.2 ± 3.6	84.3 ± 3.8	81.1 ± 4.1	86.7 ± 1.9	87.3 ± 3.5	84.5 ± 3.2	**
L6 to MP	79.8 ± 4.0	78.2 ± 3.3	78.5 ± 4.4	82.4 ± 3.2	82.9 ± 3.5	80.6 ± 3.9	84.0 ± 2.5	86.2 ± 4.6	83.6 ± 3.8	**
L7 to MP	83.7 ± 5.2	83.1 ± 3.9	83.7 ± 4.1	86.4 ± 3.7	87.0 ± 4.9	84.5 ± 4.5	88.8 ± 2.5	88.8 ± 5.2	89.4 ± 4.4	**
Occlusal Plane										
SN-OP	19.0 ± 3.0	18.2 ± 3.1	16.9 ± 2.9	20.2 ± 3.2	15.9 ± 3.1	14.1 ± 3.2	14.0 ± 3.1	12.1 ± 3.1	11.4 ± 4.2	**
FH-OP	10.2 ± 3.0	8.8 ± 2.8	8.1 ± 2.0	10.9 ± 3.5	7.4 ± 2.9	6.0 ± 3.0	7.3 ± 0.9	5.0 ± 2.9	2.9 ± 4.0	**
PP-OP	9.9 ± 2.8	9.7 ± 2.8	8.9 ± 1.7	9.9 ± 2.3	7.0 ± 2.9	6.6 ± 2.4	5.6 ± 2.4	5.3 ± 2.4	5.2 ± 3.5	**
MP-OP	17.1 ± 2.9	18.7 ± 2.5	18.7 ± 3.2	15.0 ± 2.2	14.4 ± 2.7	16.3 ± 2.6	12.2 ± 3.2	11.2 ± 3.4	12.5 ± 2.7	**
AB-OP	91.0 ± 2.1	93.5 ± 2.2	98.9 ± 1.3	88.5 ± 2.5	90.2 ± 2.1	93.9 ± 2.3	84.8 ± 2.8	91.2 ± 2.9	94.1 ± 2.2	**

p value calculated by one way ANOVA test.* $p < 0.05$, ** $p < 0.01$ Statistically significant difference.

variable (AB-MP, SN-AB, PMA, ANB) model that produced the most efficient separation between the nine types (Table 4). Since we have used Wilks' lambda as the entry criterion, variables that produced the smallest lambda for each step were selected. The F value associated with the change in Wilks' lambda (*F*-to-remove) is listed in Table 4. Maximum F to remove was set at 2.71.

Theoretically, though nine groups with many discriminating variables can produce a maximum of eight (9−1 = 8) discriminant functions, there were four functions with nonzero eigenvalues (Table 5). When

Table 2-2. Duncan's multiple range test for nine-type comparisons

Variables	Homogeneous subsets with statistically significant difference $p < 0.05$
Upper and Lower Incisor	
U1 to SN	47<7125<253<536<3698
U1 to FH	74<152<52368<23689
U1 to PP	471<712<125936<259368
L1 to SN	41<175<752<863<9
L1 to FH	417<175<52<28<86<63<39
L1 to NB	93<36<682<8257<2571<5714
L1 to MP	3<269<691<15<548<487
Inter-incisal angle	1458267<4582673<6739
Premolar and Molar	
U4 to PP	412<256739<567398
U5 to PP	412<2357<357689
U6 to PP	4123<1235<35697<6978
U7 to PP	4213<21356<35679<56798
L4 to MP	326<261<149<495<57<78
L5 to MP	32<614<145<459<597<78
L6 to MP	2315<645<4597<978
L7 to MP	23164<645<45879
Occlusal Plane	
SN-OP	98<876<765<53<321<214
FH-OP	9<86<6753<7532<5321<21<14
PP-OP	98765<3214
MP-OP	879<54<46<61<123
AB-OP	7<4<518<269<3

A sign of inequality is the borderline between the homogeneous subsets.

these functions were ranked, the first proved to have the most discriminating power, while the second was also useful. This is because the size of the eigenvalue is related to the discriminating power of that function: the larger the eigenvalue, the greater the discrimination.[10] Since the first and second eigenvalue were more than hundred times larger than the third and fourth, only the first two functions were admitted to be statistically significant. Further, the relative percentages (computed by adding all the eigenvalues and then dividing this into each individual eigenvalue) were listed in the third column of Table 5 and cumulative percentage in the fourth column. Thus, the first two functions contained 99.9% of the total discriminating power. Substantive

Table 3. Correlation coefficient between several skeletal variables and dentoalveolar measurements

	SN-AB		ANB		PMA		AB-MP	
Upper and Lower Incisor								
U1 to SN	0.615	**	−0.318	**	−0.164	**	−0.173	**
U1 to FH	0.479	**	−0.358	**	−0.119	*	−0.241	**
U1 to PP	0.328	**	−0.264	**	−0.259	**	−0.195	**
L1 to SN	0.756	**	−0.551	**	−0.310	**	−0.178	**
L1 to FH	0.638	**	−0.588	**	−0.274	**	−0.234	**
L1 to NB	−0.455	**	0.583	**	0.195	**	0.192	**
L1 to MP	−0.300	**	0.390	**	−0.346	**	0.674	**
Inter-incisal angle	0.189	**	−0.230	**	−0.140	**	−0.025	NS
Premolar and Molar								
U4 to PP	0.279	**	−0.229	**	−0.519	**	0.065	NS
U5 to PP	0.302	**	−0.232	**	−0.473	**	0.031	NS
U6 to PP	0.314	**	−0.194	**	−0.469	**	0.082	NS
U7 to PP	0.265	**	−0.108	NS	−0.403	**	0.135	*
L4 to MP	−0.084	NS	0.137	*	−0.490	**	0.612	**
L5 to MP	−0.033	NS	0.121	*	−0.518	**	0.598	**
L6 to MP	0.052	NS	0.032	NS	−0.531	**	0.539	**
L7 to MP	0.035	NS	−0.029	NS	−0.403	**	0.425	**
Occlusal Plane								
SN-OP	−0.733	**	0.304	**	0.390	**	−0.106	NS
FH-OP	−0.575	**	0.378	**	0.359	**	−0.030	NS
PP-OP	−0.380	**	0.255	**	0.636	**	−0.127	*

NS: statistically not significant, * $p < 0.05$, ** $p < 0.01$

Table 4. The result of stepwise variable selection procedure. At each step, the variable that minimizes the overall Wilks' Lambda was entered. Maximum partial F to remove was set at 2.71

Variables in model	F to Remove	Wilks' Lambda
AB-MP	28.988	.062
SN-AB	22.453	.056
PMA	7.246	.041
ANB	5.292	.039

utility of a discriminant function could be also examined by the canonical correlation coefficient. This coefficient is a measure of association that summarizes the degree of relation between the groups and the discriminant function. Higher coefficients (0.905, 0.896 respectively) were found for the first two functions, which indicated that a strong relationship exists between the types and the first two discriminant functions (Table 5). The first two discriminant function were as follows:

$$\text{Function 1} = -0.035(\text{SN-AB}) + 0.175(\text{ANB}) - 0.049(\text{PMA}) + 0.453(\text{AB-MP}) - 29.304$$

Table 5. Eigenvalues and measures of importance for the four discriminant functions. There were four nonzero eigenvalues, and they have been presented in the order of descending magnitude

Function	Eigenvalue	Relative Percentage	Cumulative Percentage	Canonical Correlation
1	4.523	52.4	52.4	.905
2	4.050	47.0	99.4	.896
3	.040	.5	99.9	.195
4	.011	.1	100.0	.106

Table 6. Standardized Canonical Discriminant Function Coefficients

Variables	Function 1	Function 2	Function 3	Function 4
AB-MP	.858	.155	-.416	.687
SN-AB	-.085	.714	.441	.621
PMA	-.123	-.494	-.367	.957
ANB	.205	-.314	1.007	-.105

Table 7. Simple classification coefficients by Fisher's linear discriminant functions

Variables	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9
AB-MP	35.321	34.402	33.097	36.473	36.191	34.903	38.064	36.937	35.971
SN-AB	18.031	18.312	19.061	17.638	18.543	19.119	18.436	19.416	19.734
PMA	15.579	15.572	15.149	15.599	14.979	14.890	14.900	14.497	14.467
ANB	-7.925	-8.714	-10.147	-7.869	-8.274	-9.149	-7.129	-9.029	-9.940
Constant	-2115.007	-2068.695	-2029.582	-2173.621	-2200.645	-2147.397	-2345.092	-2313.322	-2264.574

$$\text{Function 2} = 0.291(\text{SN-AB}) + 0.269(\text{ANB}) - 0.196(\text{PMA}) + 0.082(\text{AB-MP}) - 22.721$$

Standardized canonical discriminant function coefficients are listed in Table 6, which shows the variable's contribution to calculating the discriminant score. AB-MP (0.858) and SN-AB (0.714) showed the largest value for functions 1 and 2 respectively. The similarity between a single variable and a discriminant function, namely the structure coefficient, showed that AB-MP (0.975) carries nearly the same information as function 1. Function 2 had the highest structure coefficient, with a variable Björk-sum (0.744) that had not been entered into the discriminate analysis (Structure coefficients table not shown).

Fisher's linear combination of the discriminating variables, which maximizes group differences while minimizing variation within the groups, is listed in Table 7.

Table 8. Classification matrix to portray the accuracy of the classification procedure

Original Type	Predicted Type								
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9
Type 1	43	2	0	2	4	1	0	0	0
Type 2	3	44	0	0	0	1	0	0	0
Type 3	0	0	8	0	0	0	0	0	0
Type 4	1	0	0	18	0	0	0	0	0
Type 5	1	0	0	1	36	0	2	1	0
Type 6	2	3	4	0	3	61	0	0	2
Type 7	0	0	0	0	0	0	7	0	0
Type 8	0	0	0	0	2	0	0	23	1
Type 9	0	0	0	0	0	0	0	0	18

87.8% of original grouped cases correctly classified.

This simple classification method was expected to entail less effort and to be more clinically practical.

Table 8 is the classification matrix used to portray the accuracy of the classification procedure. Sum of correct predictions, 258, divided by total cases, 294, produced 87.8% accuracy (hit ratio).

DISCUSSION

The results clearly showed a wide range of normal variations in dentoalveolar compensation within normal occlusion samples. In fact, this study was inspired by a previously published paper on the subject by Casko and Shepherd.[3] As mentioned previously, many current systems of cephalometric evaluation that are limited to mean values would classify many of these patients as abnormal and possibly in need of correction.[3] They found that the naturally occurring ANB angle in 79 Caucasian adults with normal occlusion ranged from a 3.0 to 8.0. In this study the range of ANB angle was the same, which was also identical to the maximum value for the acceptable compromise by Steiner.[11] Our data, as compared with the Casko and Shepherd's, showed broader range of skeletal SN-MP angle (minimum 16.8 to maximum 45.3 versus 15 to 41) with less diverse dentoalveolar measurements. For example, in this study inter-incisal angle range was 125.1 to 133.6, U1 to SN 98.8 to 108.9, L1 to MP 85.9 to 103.3, whereas the data of Casko and Shepherd's was 107 to 154, 93 to 120, and 83 to 106, respectively.

The results of this study, as well as the works of Casko and Shepherd,[3] Oh,[8] Bibby,[12] Goldman,[13] Nasby,[14] Bjork and Skieller,[15] indicated that the proclined upper incisor is correlated with forward the mandibular position and the retroclined upper incisor with the backward mandibular position. The vertical skeletal pattern was also correlated with the retroclined incisors to form a normal occlusion. These are well-known phenomena of the dentoalveolar compensatory mechanism. The inter-incisal angle showed a relatively narrow range in the nine skeletal types and had low correlation coefficients with the anteroposterior and vertical skeletal variables. Thus, a relatively inert feature of the inter-incisal angle suggested the importance of the anterior incisor relationship to form a normal occlusion with an esthetic facial profile.

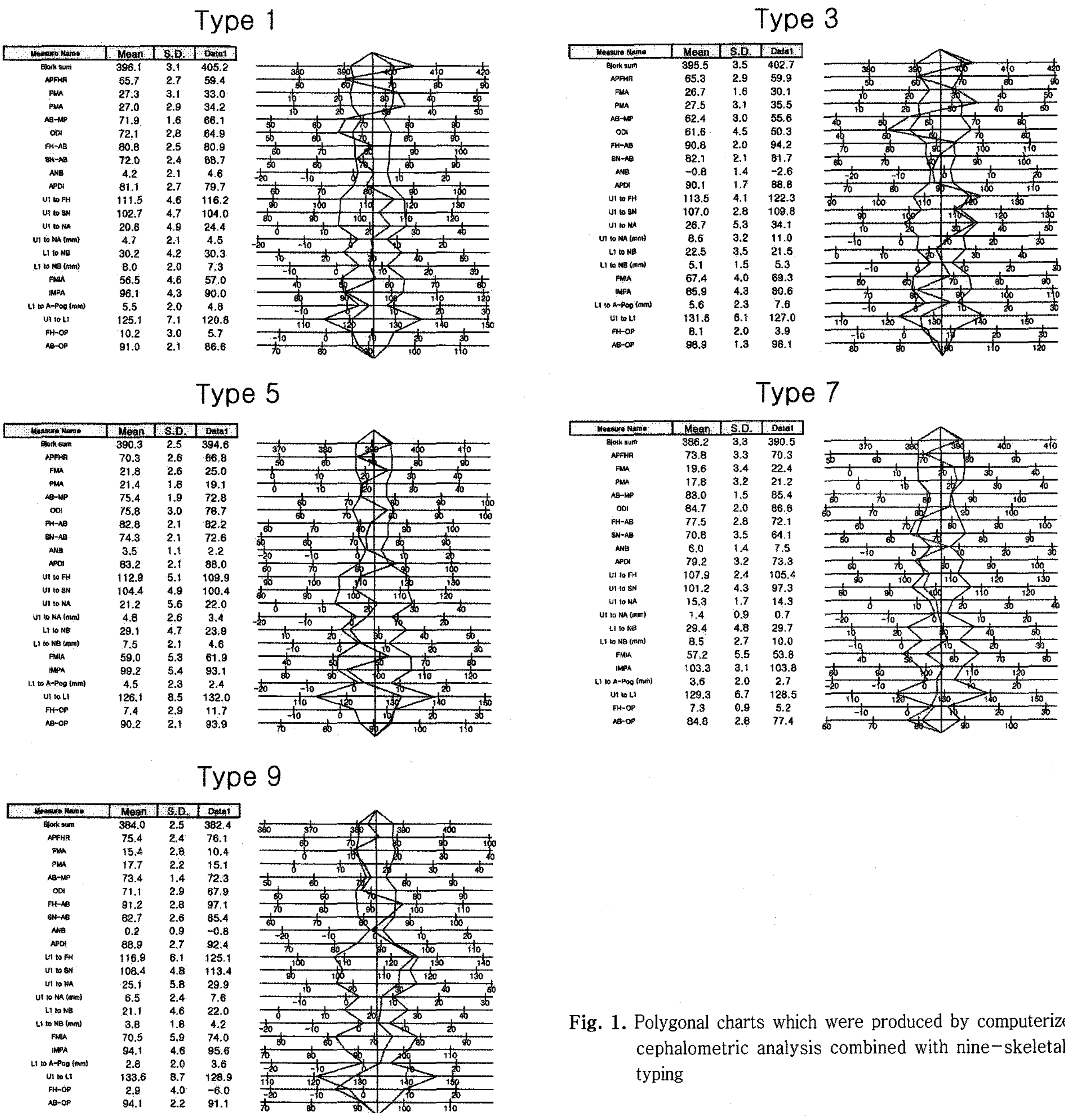
Both the anteroposterior and vertical positions of the mandible influenced the upper premolar and molar axes to the palatal plane angle. However, the lower premolar and molar axes to the mandibular plane angle were mainly influenced by the vertical mandibular position. This observation pertains to the research of Chang and Moon,[16] that included the relationship between tooth axis and vertical skeletal pattern.

Variation of the occlusal plane angle was observed, with Class II patterns showing a steep occlusal plane and Class III pattern showing a flat occlusal plane. Enlow[17] previously described the compensation mechanism of the occlusal plane adjustment during growth and development. This result could be associated with Simons' finding that a Class II molar relationship changes into a Class I molar relationship as the occlusal plane rotates downwards and backward,[18] and Jacobson's research that shows a Class III changes into a Class I as the occlusal plane rotates upwards and forward.[19]

The non-numerical evaluation of facial form developed by Fishman,[6] a graphic approach termed cephalomorphic analysis, is thought to be a more sophisticated method than the template by Moorreess[20] for establishing an individualized clinical diagnosis and treatment plan. Nowadays, a lot of cephalometric analysis is computer-based, resulting in analysis reports with 'norms' and 'variations'. Computerized cephalometric analysis combined with nine-skeletal-typing could produce nine kinds of polygonal charts (Figure 1). We attempted to create a polygonal chart for every skeletal type using Excel VBA (Visual Basic for Application, Microsoft, Vancouver, WA). Although the visual approach to classify skeletal types gives us direct intuition, mathematical computation corresponds to current the computer-based environment more harmoniously. In this respect, digitalizing cephalometric tracing, automatic classification of skeletal pattern, and analyzing dentoalveolar characteristics with individualized skeletal type could provide more valuable information than just a simple 'standardized' analysis. In our study, stepwise variable selection with discriminant analysis was performed to find several potential variables for skeletal typing and to classify the pre-determined normal occlusion samples. This method was intended to classify individual malocclusion patients.

As a result of the stepwise variable selection procedure, four variables (AB-MP, SN-AB, PMA, ANB) were extracted. The contribution of the individual variable to discriminant function could be explained by standardized canonical discriminant function coefficients. For function 1, AB-MP had the largest value, whereas for function 2, SN-AB showed the largest value, indicating these variables have the greatest contribution to calculating the discriminant score (Table 4). However, in a simple bi-variant correlation between a single variable and a discriminate function, the structure coefficient showed that function 1 is closely related with AB-MP. With function 2, the Björk-sum was the most dominant variable. Thus, function 1 could refer to the ODI dimension, if the contribution of the palatal plane angle is small. Function 2 could be called the Björk-sum dimension. Therefore, the most similar variables to statistically significant two discriminant functions create a skeletal morphology by a term of quadrangle, composed of four angular points (Sella, Gonion and two points of contact formed by SN-AB and AB-MP). This quadrangle, which classifies skeletal types, is associated with the famous Tweed[21] triangle.

Using the two canonical discriminate functions within the nine-group classification entails more labor, although mathematical operations are not so great. We reduced our work considerably by using simple classification coefficients (Table 7). This result was expected to facilitate practical classification. Retrospective classification of skeletal type executed by discriminate analysis correctly classified 87.8 % of original cases. The proportion of cases correctly classified indicates the accuracy of the procedure and indirectly confirms the degree of group separation.[10] Since we had the nine types, and the prior probability for these nine groups was only 11.1%, the hit ratio of 87.8% would be a consi-derable improvement, even though it was far from being perfect. More favorably, the types 1, 3, 7, 9, which represent skeletal extremes, showed no incorrectly classified cases (Table 8).



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

Fig. 1. Polygonal charts which were produced by computerized cephalometric analysis combined with nine-skeletal-typing

Skeletal patterns are relationships over which we have very little control in orthodontic treatment, except by the use of surgical techniques. However, in subjects with normal occlusions there were wide variations among individuals in the anteroposterior and vertical jaw relationship. In evaluating those cases that fall on the borderline between non-surgical orthodontic correction and surgical-orthodontic treatment modality, these ranges in skeletal variation would provide an additional basis for differential diagnosis. When planning treatment for patients with skeletal discrepancies, the decision of whether to include orthognathic surgery is the key to a successful outcome. With severe discrepancies in the jaw relationship, orthognathic surgery is generally required. However, for the patients with mild skeletal discrepancies and no esthetic problems, orthodontic treatment without surgery is often preferable. In these cases, differential diagnosis is often difficult. This appears to be due to lack of an objective guide for orthognathic surgery and sufficient information on skeletal relationships that could result in normal occlusions by dental adjustment.

The subjects in this study were untreated adults selected on the basis of a normal occlusion. It is reasonable to ask if some of the more extreme variations recorded in this study would result in an unacceptable profile. In fact, soft tissue limitations not reflected in this study are often a major factor in the decision for orthodontic or surgical–orthodontic treatment. While profile evaluation is, to a large degree, a subjective assessment and was not included specificity in this study, a subjective evaluation of the sample revealed no patients with extremely poor or unacceptable profiles.

While this study investigated dentoalveolar compensation according to the anteroposterior and the vertical skeletal relationships, evaluation of the transverse skeletal relationship is recommended for a study on dentoalveolar compensation in 3–dimensional plane. In addition, to establish a concrete limitation of dentoalveolar compensation and adequate diagnostic criteria for the individual cranial–facial relationship of the patients, it would be desirable to increase the number of samples and to divide the groups by gender.

In addition, an understanding of the normal variation in natural dentoalveolar compensation would greatly help in diagnosing and treatment planning. Especially in defining the range of incisal inclination and degree of occlusal plane in individuals with skeletal discrepancies that can produce esthetic and functional results without orthognathic surgery. Moreover, careful analysis of the contribution of dentoalveolar compensation to treatment results would explain many successes and failures in orthodontic treatment.

CONCLUSION

In this study, the dentoalveolar pattern in the normal occlusion sample according to the previously classified nine skeletal types was described. The diversity was relatively large and the compensation mechanism was associated with previously reported data. Nine kinds of polygonal charts were created to analyze individual malocclusion patients. Discriminant analysis was performed to establish several potential variables for skeletal typing, in order to facilitate practical classification for individual malocclusion patients. The accuracy of the classification procedure was highly acceptable when using four discriminating skeletal variables. A more extensive study with an individualized approach that includes soft tissue and three–dimensional consideration is expected

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국문초록

골격형에 따른 치아치조성 보상기전의 분석 및 골격형 판별

김지영, 김태우, 남동석, 장영일

서울대학교 치과대학 교정학교실

본 연구의 목적은 전후방 및 수직적 골격형에 따라 선험적으로 9 개의 유형(type)으로 분류된 정상교합자의 치아치조부 보상기전의 양상을 분석하고 이를 임상적으로 개별 부정교합자에게 적용이 가능한 신뢰성 있고 간편한 골격 유형의 감별기준을 도출하고자 한 것이었다. 이를 위하여 정상교합자 294명의 측모두부방사선계측치 중 치아치조부 계측 항목의 기술 통계량을 구하고 각 유형 간의 특징을 비교하기 위하여 분산 분석과 다중 비교를 시행하였으며, 골격 계측 항목과 치아치조부 계측 항목 간의 상관관계를 분석하였다. 또한 이러한 유형을 부정교합자의 개별 골격형에 적용할 수 있도록 판별 분석을 시행하여 골격형 감별의 효율성과 정확성을 가늠하였다. 그 결과 각 골격 유형별로 특징적인 치아치조부 보상기전을 확인할 수 있었으며, 상/하악 전치의 위치 및 교합 평면을 나타내는 변수에서 높은 상관관계가 관찰되었다. 판별 분석 결과 9 개의 골격 유형을 분류할 수 있는 4 개의 변수(AB- MP, SN-AB, PMA)를 구할 수 있었으며, 이들 4 개의 변수로 이루어진 판별 계수로 전체 표본의 87.8% 를 정확하게 분류할 수 있었다. 결론적으로, 이러한 연구 결과를 통해 개별 부정교합자의 개별화된 진단 및 치료 지침 수립시 기초적 정보를 제공할 수 있을 것으로 예견되었다.

주요 단어 : 골격유형, 치아치조성 보상, 판별분석