Prognostic Indicators for Anterior Mandibular Repositioning in Adolescents with Class II Malocclusion: A Cross-Sectional Cephalometric Study

Jong-Moon Chae*/ Jae Hyun Park **/ Seon-Hye Kim***/ Utkarsh Mangal**** / Hye Young Seo*****

Objective: *To investigate the cephalometric changes following anterior repositioning of the mandible for predicting the treatment effects in Class II adolescent patients.* ***Study Design:*** *Lateral cephalograms of 28 patients (ANB > 4°) were taken in centric occlusion (CO) and edge-to-edge bite (EtoE) before orthodontic treatment. The patients were classified into two groups according to their mandibular plane angle [MPA; low MPA (LMPA) ≤ 28° and high MPA (HMPA) > 28°]. Cephalometric changes of hard and soft tissues were measured and analyzed with an x-y cranial base coordinate system.* ***Results:*** *For CO to EtoE, there were no significant cephalometric changes between HMPA and LMPA, but the horizontal ratio of soft to hard tissue pogonion (H-Pog'/H-Pog) change was significantly greater with LMPA than with HMPA while the vertical ratio (V-Pog'/V-Pog) showed vice versa. For CO to EtoE, MPA showed significant correlations with H-Pog'/H-Pog and V-Pog'/V-Pog. Y-axis angle, V-Pog'/V-Pog and H-Pog'/H-Pog can be used as good tools to discriminate between HMPA and LMPA.* ***Conclusion:*** *Cephalometric findings for CO to EtoE may be useful in predicting the vertical and horizontal changes of hard and soft tissues with the treatment of growing adolescents having various vertical skeletal patterns of Class II malocclusion.*

Keywords: *Class II adolescents, Centric occlusion, Edge-to-edge bite, Cephalometric changes, Mandibular plane angle.*

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INTRODUCTION

Class II malocclusions manifest in various combinations of skeletal and dental disharmony that affect the overlying soft tissue facial profile. Characteristics of skeletal Class II patients contribute to an unfavorable facial profile.[1-5] Approximately 70% of Class II patients are diagnosed with a retrognathic mandible as the contributing factor to the associated skeletal discrepancy.[6]

In the case of a retrognathic mandible, functional appliances have been suitable treatment options in growing individuals.[7,8] Class II functional appliances enhance the mandible to move forward from centric occlusion (CO) to an edge-to-edge bite (EtoE), and the posterior teeth erupt to fill the space created by the inferior and mesial displacement of the mandible.[9] The objective of functional appliances is to change or jump the bite in the case of an excessively retrusive mandible.[10]

Forward mandibular positioning produces a neuromuscular adaptation[11] and an increase in the number of replicating cells in the temporomandibular joint, which leads to increased neovascularization and new bone formation in the condyles of growing children.[12-14] Consequently, forward positioning and maintaining the mandible in the corrected position for a sufficient amount of time

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stimulates mandibular growth.[15-18] While systematic reviews have concluded that fixed functional appliances produce a short-term effect in improving Class II malocclusion, their effects seem to be mainly dentoalveolar rather than skeletal.[19]

To predict the profile outcomes with functional appliances, pre-treatment cephalometric markers such as vertical skeletal pattern and mandibular incisor inclination have been suggested in earlier research.[20] Likewise, a better understanding of pre-treatment cephalometric values and cephalometric changes that result from intentional forward movement of the mandible may help clinicians during the treatment planning process. However, there is a lacuna of information for the preliminary cephalometric changes following anterior mandibular repositioning during registration of construction bite for functional appliance therapy in Class II adolescent patients.

To address the same, in the present study, primary cephalometric changes were evaluated to test the null hypothesis that, no significant cephalometric correlation can be established with primary mandibular advancement.

MATERIALS AND METHODS

Sample size calculation

A power analysis using G*Power (version 3.19.2; Franz Faul, Christian-Albrechts-Universitat, Kiel, Germany) was performed to estimate the sample size required for this study. In order to detect an independent sample t-test, 26 participants were required to achieve a power exceeding .80, $p = 0.05$, effect size d=0.8, two-tailed.

Subjects, eligibility criteria, and lateral cephalograms

The sample consisted of pretreatment cephalometric images at CO and EtoE positions of 28 patients (10 females, 18 males) from the Department of Orthodontics, Wonkwang University Daejeon Hospital, in Daejeon, Korea, from January 2008 to June 2017 (Table 1).

All of the subjects met the following inclusion criteria: 1) skeletal and dental Class II relationship (ANB > 4°), 2) overjet > 3.0 mm, 3) lateral cephalograms taken at CO and EtoE positions, 4) standardized lateral cephalograms of sufficient quality and resolution. The exclusion criteria for this study were subjects with any craniofacial anomaly or syndrome and subjects with a history of orthodontic treatment.

All lateral cephalograms at CO and EtoE with lips in repose were acquired using the same cephalostat (Planmeca Promax; Planmeca OY, Helsinki, Finland), with scan size, 300 × 270 mm; pixel size, 0.48 mm; field of view, 24.0 cm. The patient's head position was maintained horizontal to the Frankfort plane using a nasal positioner and positioning cones. The optimal image density and contrast were achieved at exposure settings of 64 kVp, 10 mAs, and 9.3-second scan time. The magnification factor of 1.13 was not corrected. The data were saved in Digital Imaging and Communications in Medicine (DICOM) files, and imaging software (V-Ceph, version 6.0; Osstem Inc., Seoul, Korea) was used to analyze the DICOM data to establish reference lines and generate quantitative measurements.

The institutional review board of Wonkwang University Daejeon Dental Hospital (number: WKD IRB W1804/002-001) approved the study.

Study design (cephalometric methods or assessment)

The reference points, lines, and cephalometric variables are defined in Figures 1 to 4. The horizontal reference line (HRL, x-axis) was drawn 7° to the sella-nasion line through the sella. And the vertical reference line (VRL, y-axis) was drawn perpendicular to the x-axis through the sella. The horizontal and vertical linear and angular measurements of hard and soft tissues were determined based on HRL and VRL (Figures 1-4). The subjects were classified into two groups according to their mandibular plane angle [MPA; low MPA group (LMPA) ≤ 28° and high MPA group (HMPA) > 28°] (Tables 1-4).

Table 1: Patient characteristics in CO and EtoE according to the amount of MPA at CO

Variables	Total (n = 28)				LMPA ≤ 28° (n = 15)				HMPA > 28° (n = 13)			
	CO		EtoE		CO		EtoE		CO		EtoE	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (y)	10.87	2.20	10.87	2.20	11.12	2.61	11.12	2.61	10.58	1.65	10.58	1.65
ANB (°)	6.07	1.20	2.81	1.55	5.83	0.90	2.77	1.87	6.35	1.46	2.85	1.17
MPA (°)	27.76	6.15	28.81	5.93	23.36	3.75	24.74	4.18	32.84	4.07	33.50	3.78
LOPA (°)	8.31	4.46	9.56	5.19	7.00	4.93	8.38	6.22	9.82	3.46	10.92	3.41
AC (°)	12.79	3.94	6.18	4.05	11.68	3.44	5.39	4.40	14.07	4.23	7.10	3.56
YA (°)	65.26	3.93	64.55	3.84	63.43	3.99	62.93	4.07	67.37	2.68	66.42	2.62
AEA (°)	51.52	6.30	51.52	6.30	51.13	5.10	51.13	5.10	51.97	7.64	51.97	7.64
ZA (°)	60.60	6.14	67.26	6.04	62.21	6.34	69.10	6.58	58.73	5.57	65.15	4.75
NLA (°)	101.38	9.65	101.28	8.33	103.27	7.74	103.65	7.76	99.21	11.40	98.55	8.41
MLA (°)	116.21	14.57	141.01	12.43	112.76	13.84	138.29	12.73	120.19	14.89	144.15	11.76
MLSD (mm)	5.54	1.49	3.54	1.20	5.79	1.61	3.79	1.26	5.26	1.35	3.24	1.09
EL to UL (mm)	4.15	2.54	1.61	2.54	3.93	3.15	1.48	3.07	4.39	1.66	1.77	1.88
EL to LL (mm)	3.02	2.38	2.81	2.59	2.41	2.83	2.26	3.29	3.73	1.55	3.44	1.27

CO, centric occlusion; EtoE, edge-to-edge bite; MPA, mandibular plane angle; LOPA, lower occlusal plane angle; AC, angle of convexity (NA to A-Pog); YA, Y-axis angle (S-Gn to HRL); AEA, articular eminence angle; ZA, Z angle; NLA, nasolabial angle; MLA, mentolabial angle; MLSD, mentolabial sulcus depth; EL, esthetic line; UL, upper lip; LL, lower lip; LMPA, low MPA group; HMPA, high MPA group.

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Figure 1. Skeletal, dental and soft tissue landmarks and reference lines used in cephalometric analysis.

S, sella; N, nasion; UAE, upper articular eminence; LAE, lower articular eminence; Go, gonion; A, point A; B, point B; Pog, pogonion; Gn, gnathion; Me, menton; L1, mandibular central incisor crown tip; L6, mesiobuccal cusp tip of mandibular first molar; Pn, pronasale; Cm, columella; Sn, subnasale; Ls, labrale superius; UL, upper lip; LL, lower lip; Li, labrale inferius; B′, soft tissue point B; Pog′, soft tissue pogonion; Me′, soft tissue menton; HRL, horizontal reference line (SN-7° at S); VRL, vertical reference line (perpendicular to SN-7° at S).

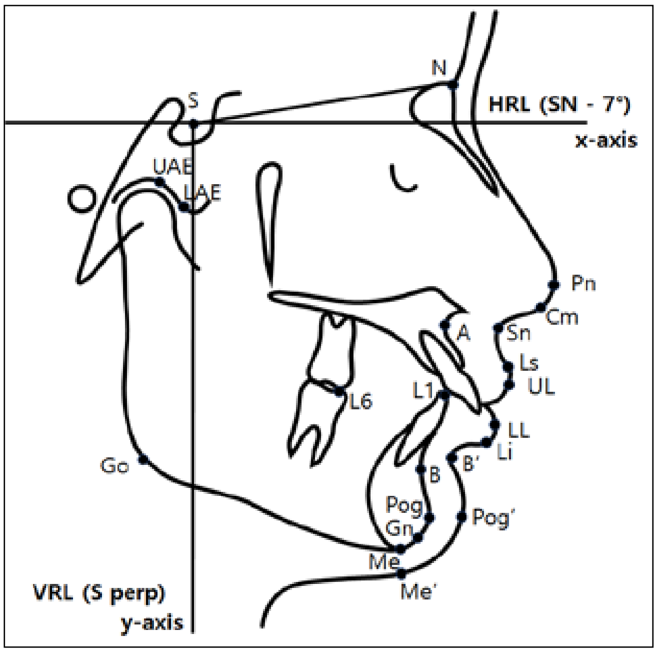

Figure 2. Vertical and horizontal linear measurements of hard tissue.

HRL, horizontal reference line; VRL, vertical reference line; L1, B, Pog and Me to HRL and VRL.

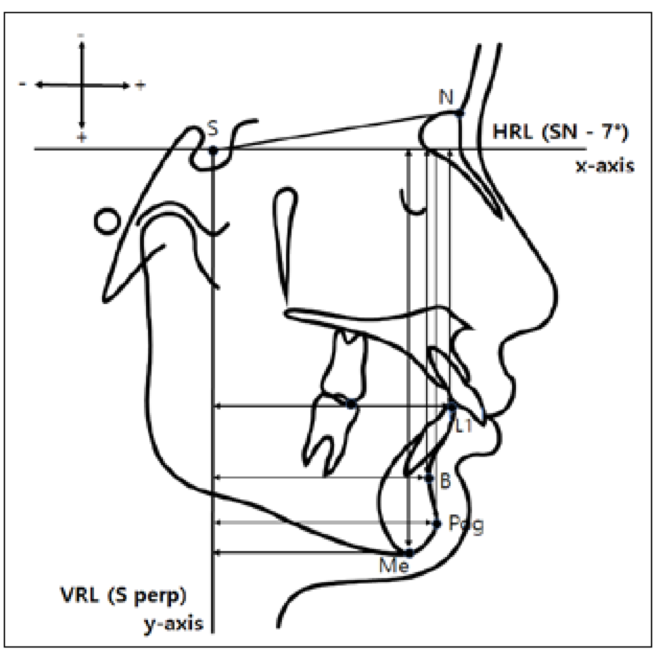

Figure 3. Vertical and horizontal linear measurements of soft tissue.

HRL, horizontal reference line; VRL, vertical reference line; LL, B′, Pog′ and Me′ to HRL and VRL; MLSD, mentolabial sulcus depth; E-line to UL and LL.

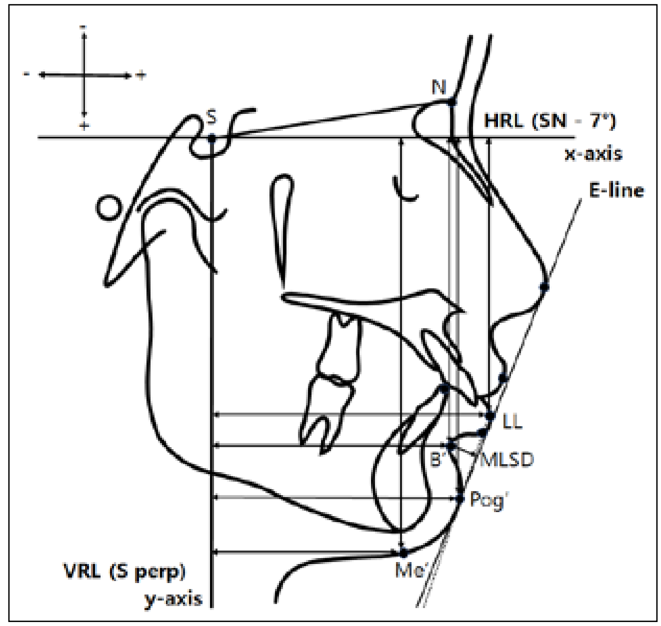

Figure 4. Angular measurements.

HRL, horizontal reference line; VRL, vertical reference line; MPA, mandibular plane angle; MOPA, mandibular occlusal plane angle; AEA, articular eminence angle; YA, Y-axis angle (S-Gn to HRL); AC, angle of convexity (NA to A-Pog); ANB angle; ZA, Z angle; NLA, nasolabial angle; MLA, mentolabial angle.

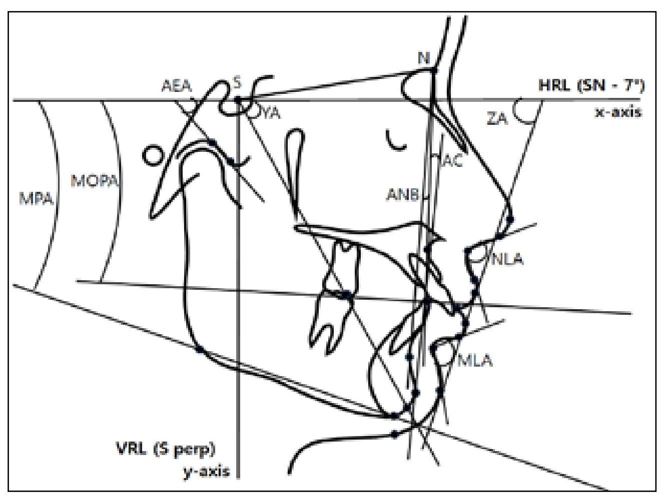

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Table 2: Cephalometric differences between LMPA and HMPA in CO and EtoE according to the amount of MPA at CO

Variables	CO			EtoE		
	LMPA-HMPA			LMPA-HMPA		
	Mean	SD	P	Mean	SD	P
Age (y)	0.54	0.84	.526	0.54	0.84	.526
ANB (°)	-0.52	0.45	.256	-0.09	0.60	.888
MPA (°)	-9.48	1.48	.000*** (.000***)	-8.76	1.51	.001***
LOPA (°)	-2.81	1.63	.097 (.072)	-2.24	1.94	.201
AC (°)	-2.40	1.45	.110	-1.71	1.53	.275
YA (°)	-3.93	1.31	.006**	-3.48	1.32	.014* (.015*)
AEA (°)	-0.84	2.43	.732	-1.26	2.26	.626
ZA (°)	3.48	2.27	.137	3.95	2.20	.084
NLA (°)	4.05	3.64	.278	5.10	3.06	.107
MLA (°)	-7.43	5.43	.183	-5.87	4.66	.219
MLSD (mm)	-0.53	0.57	.360	-0.55	0.45	.233
EL to UL (mm)	-0.46	0.98	.639	-0.29	0.98	.770
EL to LL (mm)	-1.32	0.88	.146	-1.18	0.92	.214

**p* < 0.05, ***p* < 0.01, ****p* < 0.001.

CO, centric occlusion; EtoE, edge-to-edge bite; MPA, mandibular plane angle; LOPA, lower occlusal plane angle; AC, angle of convexity (NA to A-Pog); YA, Y-axis angle (S-Gn to HRL); AEA, articular eminence angle; ZA, Z angle; NLA, nasolabial angle; MLA, mentolabial angle; MLSD, mentolabial sulcus depth; EL, esthetic line; UL, upper lip; LL, lower lip; LMPA low MPA group; HMPA, high MPA group.

If normality was not satisfied, the Mann-Whitney U test results were presented in ( ).

Table 4: The ratios of soft to hard tissue changes between LMPA and HMPA from CO to EtoE according to the amount of MPA at CO

Ratio	Total (n = 28)		LMPA ≤ 28 (n = 15)		HMPA > 28 (n = 13)		P
	Mean	SD	Mean	SD	Mean	SD	
V-Me′ / V-Me	0.80	0.10	0.82	0.09	0.78	0.12	.304 (.201)
V-Pog′ / V-Pog	0.70	0.29	0.85	0.24	0.53	0.25	.002**
V-B′ / V-B	0.60	0.25	0.62	0.24	0.57	0.27	.615
V-LL / V-L1	0.31	0.23	0.35	0.15	0.20	0.29	.384
H-Me′ / H-Me	1.03	0.40	1.06	0.47	1.00	0.33	.721 (.467)
H-Pog′ / H-Pog	1.02	0.38	0.87	0.36	1.19	0.33	.023* (.010*)
H-B′ / H-B	1.32	0.35	1.35	0.32	1.28	0.39	.569 (.467)
H-LL / H-L1	0.61	0.38	0.56	0.29	0.67	0.47	.457 (.892)

**p* < 0.05, ***p* < 0.01.

V, vertical linear measurement; H, horizontal linear measurement; Me, menton; Me′, soft tissue menton; Pog, pogonion; Pog′, soft tissue pogonion; B, point B; B′, soft tissue point B; LL, lower lip; L1, mandibular central incisor crown tip; CO, centric occlusion; EtoE, edge-to-edge bite; LMPA, low MPA group; HMPA, high MPA group.

If normality was not satisfied, the Mann-Whitney U test results were presented in ( ).

Table 3: Cephalometric changes between LMPA and HMPA from CO to EtoE according to the amount of MPA at CO

Variables	Total (n = 28)		LMPA ≤ 28° (n = 15)		HMPA > 28° (n = 13)		P
	Mean	SD	Mean	SD	Mean	SD	
ANB (°)	-3.26	1.33	-3.06	1.31	-3.50	1.36	.395
MPA (°)	1.05	1.13	1.38	1.10	0.66	1.07	.091
LOPA (°)	1.25	3.09	1.38	3.90	1.11	1.91	.823 (.496)
AC (°)	-6.61	2.51	-6.28	2.53	-6.98	2.55	.478
YA (°)	-0.71	0.84	-0.50	0.90	-0.95	0.74	.162
ZA (°)	6.67	4.05	6.88	4.03	6.42	4.22	.767
NLA (°)	-0.11	5.18	0.38	4.53	-0.67	5.97	.602
MLA (°)	24.80	11.01	25.52	7.93	23.96	14.07	.715
MLSD (mm)	-2.01	0.94	-2.00	0.88	-2.02	1.03	.954
EL to UL (mm)	-2.54	1.41	-2.45	1.26	-2.63	1.62	.753
EL to LL (mm)	-0.22	1.46	-0.15	1.33	-0.29	1.64	.807

CO, centric occlusion; EtoE, edge-to-edge bite; MPA, mandibular plane angle; LOPA, lower occlusal plane angle; AC, angle of convexity (NA to A-Pog); YA, Y-axis angle (S-Gn to HRL); AEA, articular eminence angle; ZA, Z angle; NLA, nasolabial angle; MLA, mentolabial angle; MLSD, mentolabial sulcus depth; EL, esthetic line; UL, upper lip; LL, lower lip; LMPA, low MPA group; HMPA, high MPA group.

If normality was not satisfied, the Mann-Whitney U test results were presented in ( ).

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Statistical analysis

One investigator (J.M.C.) performed all the measurements on the 28 subjects. To test the reliability of the measurements, twenty CO and EtoE lateral cephalograms were randomly selected for re-measurement two-weeks after the initial measurement. The intraclass correlation coefficient showed excellent test-retest reliability, ICC = 0.98. The standard errors of measurement were: 0.81(CO) and 7.03 (EtoE).

SPSS software (version 24.0 for Windows; SPSS Corp., Chicago, IL) was used for statistical analyses. A Shapiro-Wilk normality test was performed and a nonparametric test was used whenever normality was not satisfied.

An independent sample t-test or Mann-Whitney U test was used to compare cephalometric differences between LMPA and HMPA in CO and EtoE, and cephalometric changes and ratios of soft to hard tissue changes between LMPA and HMPA from CO to EtoE according to the amount of MPA at CO. If normality was not satisfied, the Mann-Whitney U test results were presented together.

Pearson correlation analyses between the variables and MPA in CO and EtoE, between the cephalometric changes and MPA, and between the ratios of soft to hard tissue changes and MPA was performed.

Receiver operating characteristic (ROC) curves and area under the curves (AUC) of the variables were calculated to assess the diagnostic specificity.

RESULTS

For CO, mean value of overjet was 6.29 ± 2.36 mm with a range from 3.07 to 11.36 mm (LMPA, 5.80 ± 2.49 mm; HMPA, 6.85 ± 2.16 mm), and mean value of overbite was 7.16 ± 1.54 mm with a range from 4.84 to 10.74 mm (LMPA, 7.33 ± 1.61 mm; HMPA, 6.97 ± 1.49 mm).

With CO and EtoE, most values were greater in HMPA than in LMPA, but Z angle, nasolabial angle and mentolabial sulcus depth were greater in LMPA than HMPA (Table 1), and Y-axis angle was significantly greater in HMPA than in LMPA with CO ($p < 0.01$) and EtoE ($p < 0.05$) (Table 2).

From CO to EtoE, the MPA, mandibular occlusal plane angle, Z angle and mentolabial angle increased more in LMPA than in HMPA. Whereas, the ANB angle, angle of convexity, Y-axis angle, mentolabial sulcus depth, and esthetic line to upper and lower lips decreased more in HMPA than in LMPA, showing a statistical insignificance (Table 3).

From CO to EtoE, the ratios of soft to hard tissue changes were greater horizontally than vertically. The horizontal ratio in the menton (1.03:1) and horizontal ratio in the pogonion (1.02:1) were almost 1:1, while others are less than 1:1 except for the horizontal ratio at point B (1.3:1). The vertical ratio in the pogonion (0.70:1, $p < 0.01$) and the horizontal ratio in the pogonion (1.02:1, $p < 0.05$) showed a statistically significant difference between LMPA (0.85:1 and 0.87:1) and HMPA (0.53:1 and 1.19:1), respectively. The horizontal ratio at point B (1.32:1) was the greatest while the vertical ratio of lip to incisor in the mandible was the least (0.31:1). Most ratios were greater in LMPA than in HMPA, but the horizontal ratio in the pogonion and lip to incisor in the mandible were greater in HMPA than in LMPA (Table 4).

For CO, MPA showed significant positive correlations with Y-axis angle (r=0.846, $p < .001$), ANB (r=0.464, $p < 0.05$), mandibular occlusal plane angle (r=0.459, $p < 0.05$) and angle of convexity (r=0.456, $p < 0.05$) in that order, and a significant negative correlation with Z angle (r=-0.425, $p < 0.05$). For EtoE, MPA showed significant positive correlations with Y-axis angle (r=0.791, $p < 0.001$) and mentolabial angle (r=-0.406, $p < 0.05$) in that order, and a significant negative correlation with Z angle (r=-0.500, $p < 0.01$) (Table 5-1).

Table 5-1: Correlation analysis between the variables and MPA in CO and EtoE according to the amount of MPA at CO

Variables	CO (n = 28)		EtoE (n = 28)	
	r	P	r	P
ANB (°)	.464	.013*	.210	.284
LOPA (°)	.459	.014*	.371	.052
AC (°)	.456	.015*	.371	.052
YA (°)	.846	.000***	.791	.000***
AEA (°)	.231	.236	.224	.253
ZA (°)	-.425	.024*	-.500	.007**
NLA (°)	-.062	.755	-.172	.382
MLA (°)	.317	.100	.406	.032*
MLSD (mm)	.210	.284	.358	.062
EL to UL (mm)	-.096	.628	-.105	.595
EL to LL (mm)	.162	.410	.139	.480

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

CO, centric occlusion; EtoE, edge-to-edge bite; MPA, mandibular plane angle; LOPA, lower occlusal plane angle; AC, angle of convexity (NA to A-Pog); YA, Y-axis angle (S-Gn to HRL); AEA, articular eminence angle; ZA, Z angle; NLA, nasolabial angle; MLA, mentolabial angle; MLSD, mentolabial sulcus depth; EL, esthetic line; UL, upper lip; LL, lower lip.

For CO to EtoE, MPA showed no significant correlation with cephalometric changes but showed significant positive correlation with the horizontal ratio in the pogonion (r=0.466, $p < 0.05$) and significant negative correlation with the vertical ratio in the pogonion (r=-0.538, $p < 0.01$) (Table 5-2).

ROC curve analysis on the cephalometric changes and ratios showed that the Y-axis angle, V-Pog′/V-Pog and H-Pog/H-Pog can be used as good tools to discriminate between HMPA and LMPA because the discrimination accuracy was in a medium and accurate range with the boundary scores as in Table 6 and Figure 5.

DISCUSSION

It has been reported that hypodivergent skeletal pattern can be used as a predictor of favorable soft-tissue profile changes in response to functional appliance treatment.[20] In our study, original esthetic variables such as the angle of convexity, Z angle and the esthetic line to the upper and lower lips showed more favorable values in LMPA than in HMPA at both CO and EtoE (Table 1 and Figure 6). Therefore, the initial patient variables may affect the patient's soft tissue response to hard tissue change,[21] so a careful and differential diagnosis of the cephalometric measurements is essential in predicting soft tissue profile changes.

The Y-axis angle has been used as an indicator of vertical development and rotational change of the mandible. Lulla and Gianelly[22] noted that the correlation of mandibular plane angle with

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Table 5-2: Correlation analysis between the changes of different variables from CO to EtoE and MPA at CO

Variables / Cephalometric changes	r	P
ANB (°)	.173	.379
MPA (°)	.284	.142
LOPA (°)	.040	.839
AC (°)	.117	.555
YA (°)	.333	.083
AEA (°)	-.019	.923
ZA (°)	.101	.608
NLA (°)	.161	.412
MLA (°)	-.038	.847
MLSD (mm)	-.123	.533
EL to UL (mm)	.017	.930
EL to LL (mm)	.018	.926
Ratios		
V-Me′ / V-Me	-.099	.616
V-Pog′ / V-Pog	-.538	.003**
V-B’ / V-B	.152	.439
V-LL / V-L1	.001	.995
H-Me′ / H-Me	-.079	.691
H-Pog′ / H-Pog	.466	.012*
H-B′ / H-B	-.094	.633
H-LL / H-L1	.129	.511

*$p < 0.05$, **$p < 0.01$.

CO, centric occlusion; EtoE, edge-to-edge bite; MPA, mandibular plane angle; LOPA, lower occlusal plane angle; AC, angle of convexity (NA to A-Pog); YA, Y-axis angle (S-Gn to HRL); AEA, articular eminence angle; ZA, Z angle; NLA, nasolabial angle; MLA, mentolabial angle; MLSD, mentolabial sulcus depth; EL, esthetic line; UL, upper lip; LL, lower lip; V, vertical linear measurement; H, horizontal linear measurement; Me, menton; Me′, soft tissue menton; Pog, pogonion; Pog′, soft tissue pogonion; B, point B; B′, soft tissue point B; LL, lower lip; L1, mandibular central incisor crown tip.

Table 6: Receiver operating characteristic (ROC) curve analysis to verify the diagnostic specificity and utility of the variables

Variables / Cephalometric changes	AUC	SE	P	95% CI LCI	95% CI HCI
ANB (°)	0.59	0.11	.434	0.37	0.81
MPA (°)	1.00	0.00	.000	1.00	1.00
LOPA (°)	0.70	0.10	.072	0.50	0.90
AC (°)	0.62	0.11	.289	0.40	0.83
YA (°)	0.79	0.08	.008**	0.63	0.96
AEA (°)	0.54	0.12	.695	0.32	0.77
ZA (°)	0.33	0.10	.134	0.13	0.54
NLA (°)	0.42	0.11	.475	0.20	0.64
MLA (°)	0.67	0.11	.123	0.46	0.88
MLSD (mm)	0.60	0.11	.369	0.39	0.81
EL to UL (mm)	0.56	0.11	.580	0.34	0.78
EL to LL (mm)	0.65	0.11	.174	0.44	0.86
Ratios					
V-Me′ / V-Me	0.35	0.11	.189	0.14	0.57
V-Pog′ / V-Pog	0.17	0.08	.003**	0.02	0.33
V-B’ / V-B	0.43	0.11	.534	0.21	0.65
V-LL / V-L1	0.41	0.12	.420	0.18	0.64
H-Me′ / H-Me	0.42	0.11	.447	0.20	0.63
H-Pog′ / H-Pog	0.78	0.09	.011*	0.61	0.96
H-B′ / H-B	0.42	0.11	.447	0.20	0.64
H-LL / H-L1	0.48	0.11	.872	0.26	0.70

*$p < 0.05$, **$p < 0.01$.

CO, centric occlusion; EtoE, edge-to-edge bite; MPA, mandibular plane angle; LOPA, lower occlusal plane angle; AC, angle of convexity (NA to A-Pog); YA, Y-axis angle (S-Gn to HRL); AEA, articular eminence angle; ZA, Z angle; NLA, nasolabial angle; MLA, mentolabial angle; MLSD, mentolabial sulcus depth; EL, esthetic line; UL, upper lip; LL, lower lip; V, vertical linear measurement; H, horizontal linear measurement; Me, menton; Me′, soft tissue menton; Pog, pogonion; Pog′, soft tissue pogonion; B, point B; B′, soft tissue point B; LL, lower lip; L1, mandibular central incisor crown tip. In the ROC curve, the state variable is HMPA.

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the Y-axis angle was relatively weak, but in our study, Y-axis angle was significantly greater in HMPA than in LMPA at both CO and EtoE (Tables 1 and 2) and showed significant positive correlation with MPA (Tables 5 and 7). Ahn and Schneider[23] concluded that the horizontal position of the chin showed a high correlation with changes in the Y-axis angle. Therefore, an increase in the Y-axis angle might produce a more backward positioning of the chin with HMPA than with LMPA.

The articular eminence grows symmetrically at a very rapid rate, attaining almost half of its maturity in the first two years of life.[24] The condylar path inclination angle also increases with age,[25] but the height of the articular eminence is not affected by the use of mandibular protrusive appliances,[26] so condylar inclination might be an important factor in the decision to use mandibular protrusive appliances. In our study, the articular eminence angle was not a significant factor for hard and soft tissue changes with forward mandibular movement (Tables 1 and 2). This might be a limitation of this study because bone remodeling or new bone formation at the condyle and the glenoid would result from functional appliance treatment.[15-18]

Z angle,[27] nasolabial angle,[28] mentolabial angle,[29] mentolabial sulcus depth[30] and esthetic line to upper and lower lips[31] have been used to quantify facial balance. In this study, we divided the patients into two groups according to the amount of MPA and evaluated

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Figure 5. Graphical representation of receiver operating characteristic (ROC) curve comparing the 1-specificity and sensitivity of changes: A, cephalometric changes; B, ratios of soft tissue to hard tissue changes. In the ROC curve, the state variable is HMPA.

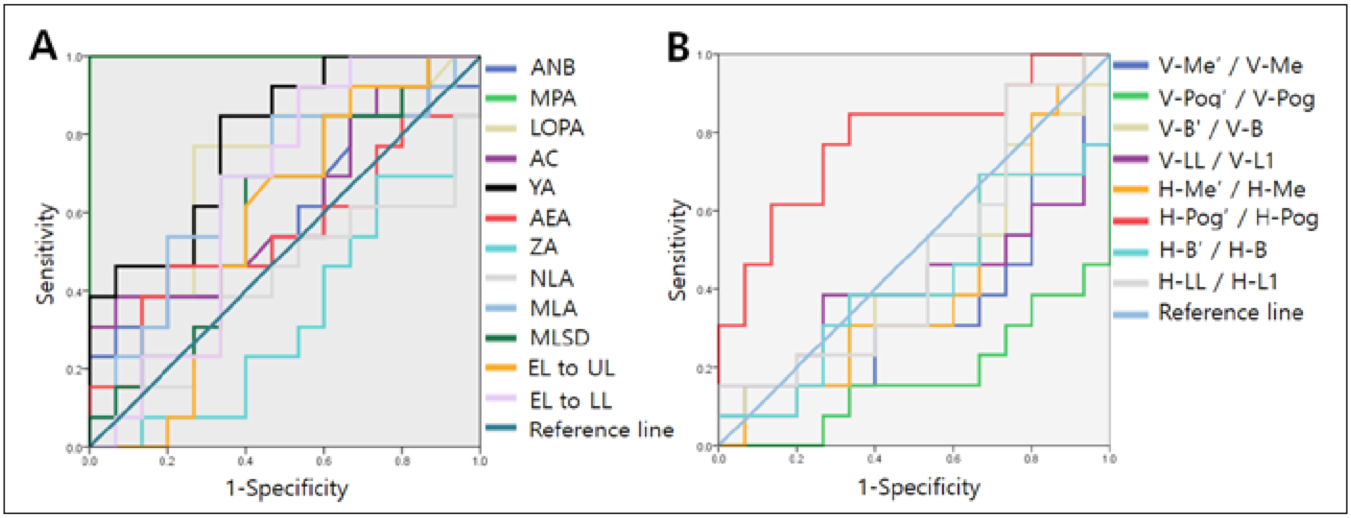
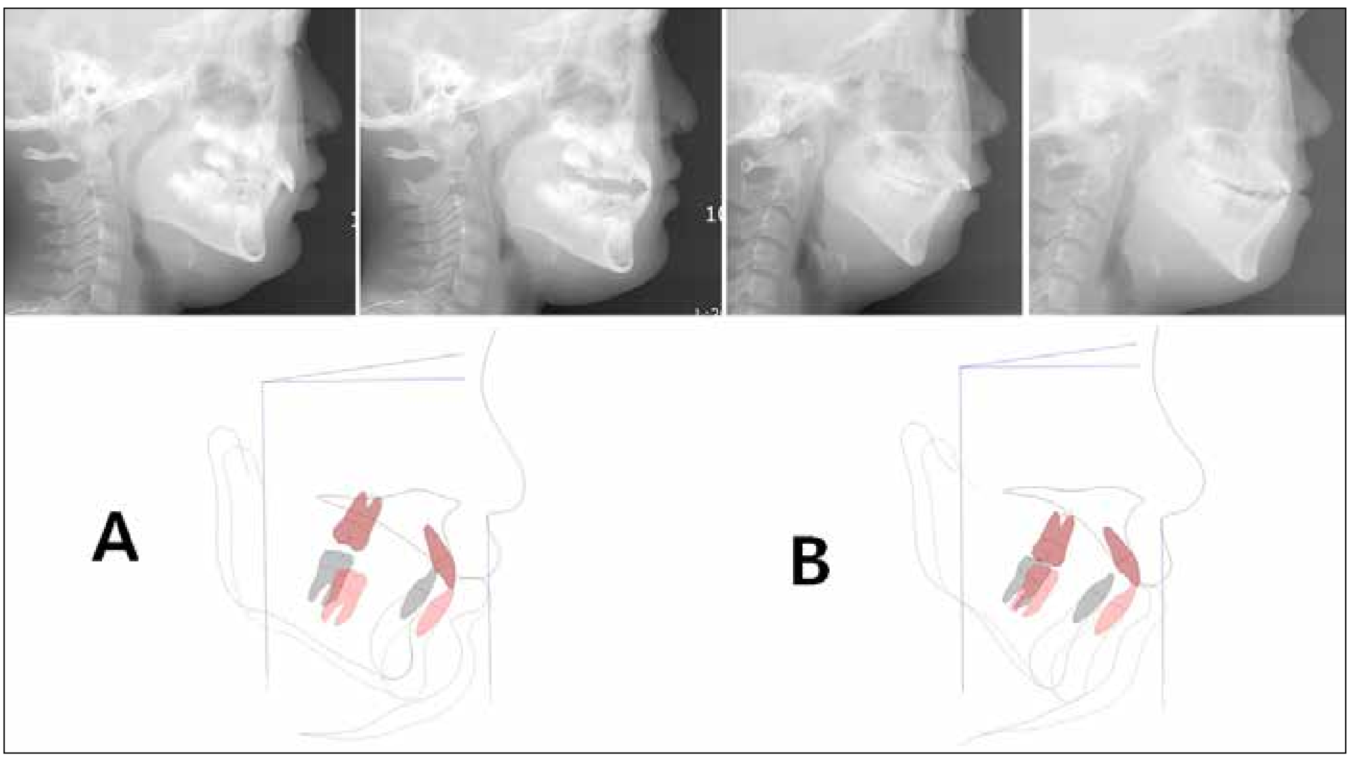


Figure 6. Lateral cephalometric radiographs in centric occlusion (CO) and edge-to-edge occlusion (EtoE), and superimposition: A, LMPA; B, HMPA.



the factors which can influence the prognosis of facial profile. Z angle and mentolabial angle increased more esthetically with LMPA than with HMPA, but the esthetic line to the upper and lower lip values was reduced esthetically more with HMPA than with LMPA. However, there were no factors that could be directly used to predict a change in the facial profile. (Tables 3 and 6).

The ratios of soft to hard tissue changes for CO to EtoE were different at each landmark. The horizontal ratios were greater than the vertical ratios at all landmarks. The vertical ratio at the pogonion was significantly greater with LMPA than with HMPA, but the horizontal ratio at the pogonion was significantly greater with HMPA than with LMPA. These results might be caused by a different path of mandibular movement for CO to EotE, depending on the vertical skeletal pattern.[32] Moreover, MPA also showed significant correlations with the ratio of soft to hard tissue changes in the pogonion, making the pogonion an important factor for prediction of soft tissue changes relative to hard tissue correction (Tables 4 and 6).

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This study demonstrated that it is possible to prognostically determine the outcome of functional appliance treatment by examining cephalometric changes during the forward positioning of the mandible (Figures 5 and 6). However, the influence of variables such as dental movement, incremental advancement[33] and relapse cannot be studied cross-sectionally. Therefore, future studies are recommended to compare the predictive and posttreatment results according to different vertical skeletal patterns.

CONCLUSIONS

Thus, with the outcomes of the present study, the null hypothesis could be rejected drawing the following conclusions for cephalometric relations:

1. Y-axis angle was significantly greater with HMPA than with LMPA in both CO and EtoE.
2. For CO to EtoE, the horizontal ratio of soft to hard tissue pogonion (H-Pog′/H-Pog) change was significantly greater with LMPA than with HMPA while the vertical ratio (V-Pog′/V-Pog) showed vice versa.
3. For CO, MPA showed significant positive correlations with Y-axis angle, ANB, mandibular occlusal plane angle and angle of convexity in that order, and a significant negative correlation with Z angle.
4. For EtoE, MPA showed significant positive correlations with the Y-axis angle and mentolabial angle in that order, and a significant negative correlation with Z angle.
5. For CO to EtoE, MPA showed significant correlations with H-Pog′/H-Pog and V-Pog′/V-Pog.
6. Y-axis angle, V-Pog′/V-Pog and H-Pog′/H-Pog can be used as good tools to discriminate between HMPA and LMPA.

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