Correlation of masticatory muscle activity and occlusal function with craniofacial morphology
: a prospective cohort study

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Correlation of masticatory muscle activity and occlusal function with craniofacial morphology : a prospective cohort study

Directed by Professor Yoon Jeong Choi

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This certifies that the Doctoral Dissertation

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감사의 글

부족한 저를 관심과 사랑으로 이끌어 주시고, 학위 과정에서 수많은 조언과 지도를 해 주신 최윤정 지도 교수님께 제일 먼저 감사의 말씀을 드립니다. 또한 관심과 격려로 논문 심사를 맡아 주신 김경호 교수님, 차정열 교수님, 안형준 교수님, 양일형 교수님께도 감사드립니다.

교정학에 입문하여 깊이 있는 공부를 할 수 있게 격려해 주시고 교정의사로서 멘토 이자 후배들에게 귀감이 되어 주시는 플러스원 치과 이주영 원장님께도 깊은 감사의 마음을 드립니다.

마지막으로 치과의사로서 학업과 병원일, 가정생활을 함께 해 나갈 수 있게 물심양면으로 도와 주신 부모님과 연세대학교 치과대학원을 시작할 때 돌쟁이 아기에서 어엿한 6 학년 어린이로 올바르게 성장한 아들 윤호에게 사랑과 감사의 말을 전합니다.

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Masticatory function, including masticatory muscle activity and occlusal function, can be affected by craniofacial morphology. This study aimed to investigate the relationship between craniofacial morphology and masticatory function in participants who had completed orthodontic treatment at least two years before and had stable occlusion.

Forty-two healthy participants were prospectively enrolled and divided into three vertical cephalometric groups according to the mandibular plane angle. Masticatory muscle activity (MMA) in the masseter and anterior temporalis muscles was assessed using surface electromyography. The occlusal contact area (OCA) and occlusal force (OF), defined as occlusal function in this study, were evaluated using occlusal pressure mapping system. Masticatory muscle efficiency (MME) was calculated by dividing MMA by OF. The craniofacial morphology was analyzed using a lateral cephalogram. The masticatory function was compared using one-way analysis of variance. Pearson correlations were used to assess relationships between craniofacial morphology and masticatory function.

The hypodivergent group had the lowest MMAand the highest MME in the masseter (167.32 ± 74.92 μN and 0.14 ± 0.06 μN/N, respectively) and anterior temporalis muscles (0.18 ± 0.08 μN/N, $p < 0.05$). MMA in the masseter showed a positive relationship with mandibular plane angle (r = 0.358), whereas OCA (r = -0.422) and OF (r = -0.383) demonstrated a negative relationship ($p < 0.05$). The anterior temporalis muscle activity negatively correlated with ramus height (r = -0.364, $p < 0.05$).

Vertical craniofacial morphology was related to masticatory function. Hypodivergent individuals may have low MMA and high occlusal function, resulting in good masticatory muscle efficiency. Hypodivergent individuals require careful consideration in orthodontic diagnosis and prosthetic treatment planning.

Keywords: craniofacial morphology, masticatory function, masticatory muscle activity, occlusal function

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I. Introduction

Several articles have reported the relationship between morphology and function in the craniofacial region. Since Moss and Salentijin (Moss and Salentijn, 1969) hypothesized that facial growth follows the growth of the functional matrix, it is widely acknowledged that craniofacial morphology is closely related with local environmental factors, such as muscles and airways. The masticatory function is a complex performance affected by several physiological factors (Bilt, 2015). During mastication, the elevator muscles of the jaw generate occlusal force, leading to the functional tooth unit making contact. Therefore, the number of teeth, occlusal force, masticatory muscle, temporomandibular joint, sex, age, body size, and general health status can influence masticatory function. Assessment of masticatory muscle activity (MMA) and occlusal function is crucial for diagnosing and managing various conditions related to masticatory function, such as temporomandibular disorders, malocclusions, or prosthodontic treatment planning (Hatch et al., 2001; Lujan-Climent et al., 2008).

Surface electromyography (sEMG) and occlusal pressure mapping system have been widely used to assess MMA and occlusal function, respectively (Suvinen and Kemppainen, 2007; Yoon et al., 2017). The contraction of the anterior temporalis leads to the jaw elevation followed by the closing of the mouth, whereas the masseter contracts during grinding and chewing (Nishi et al., 2018). sEMG can evaluate masticatory muscle function in a simple and noninvasive manner by detecting the muscle activity from the skin above the muscle (Suvinen and Kemppainen, 2007). Previous studies using sEMG have reported the relationship between craniofacial morphology and masticatory function (Cha et al., 2007; Gomes et al., 2010; Singh et al., 2012; Tecco et al., 2007; Ueda et al., 1998) with the daytime MMA showing a correlation with the vertical craniofacial morphology (Ueda et al., 1998). The Dental Prescale System (Dental Prescale II, GC, Tokyo, Japan) is a specialized occlusal pressure mapping system used for occlusal analysis in dentistry. It is a diagnostic tool that provides information on the distribution of occlusal contact area (OCA) and the magnitude of occlusal force (OF) simultaneously applied during biting and chewing (Huang et al., 2022; Kwon et al., 2022; Yoon et al., 2017). OF in this study refers to the amount of force applied to the occlusal surfaces of the maxillary and mandibular teeth during the MVC. Individuals with high OF have hypodivergent vertical relationships, such as short anterior facial height, long posterior facial height, small mandibular plane angle, and long mandibular ramus, whereas sagittal skeletal relationships are rarely correlated(Quiudini et al., 2017).

Previous studies investigating the relationship between MMA and craniofacial morphology have yielded conflicting results. The discrepancies could potentially be attributed to the lack of clarity in defining normal occlusion and to the insufficient consideration of occlusal function (Cha et al., 2007; Gomes et al., 2010; Singh et al., 2012; Tecco et al., 2007; Ueda et al., 1998). Those investigations used Angle's classification or no malocclusion to define normal occlusion. However, morphological definition of normal occlusion does not necessarily imply normal function, as identification of normal occlusion based on molar and canine relationships has a limited impact on the level of occlusal force (Huang et al., 2022). Therefore, when selecting participants with normal occlusion, consideration should be given not only to the occlusal relationship but also to the functional aspect. Although the influence of occlusion on MMA is well-documented (Ferrario et al., 2002; Wang et al., 2010), there appears to be a paucity of studies that consider both MMA and occlusal function when assessing overall masticatory function. It might be beneficial, therefore, to ensure that both of these crucial components are incorporated in evaluations of the masticatory function.

Moreover, previous studies excluded the participants with a history of orthodontic treatment (Cha et al., 2007; Gomes et al., 2010; Singh et al., 2012). Orthodontic treatment can improve occlusal function by achieving stable occlusion under the craniofacial morphology (Zanon et al., 2022). Furthermore, it is generally known that occlusal function improves over time rather than immediately after orthodontic treatment (Dinçer et al., 2003; Yoon et al., 2017). Therefore, it can be expected that individuals who have undergone orthodontic treatment would exhibit normal occlusion, both in terms of morphology and function.

This study aimed to evaluate the relationship between craniofacial morphology and masticatory function in participants who had achieved normal occlusion after completing orthodontic treatment at least 2 years prior. Masticatory function was investigated via MMA in the masseter and anterior temporalis muscles, and through occlusal function, which included occlusal contact area (OCA) and occlusion force (OF). The study included only those participants who exhibited an OCA greater than that typically reported in individuals with normal occlusion (Yoon et al., 2010). In conducting this study, we tested the null hypothesis that there is no relation between craniofacial morphology and masticatory function.

II. Materials and Methods

1. Participants

This study was conducted prospectively after receiving approval from the Institutional Review Board of the Yonsei University Dental Hospital (IRB No. 2-2020-0057). Informed consent was obtained from each participant before the examination. According to the study flow chart, the participants were sequentially enrolled among 320 patients who visited the Yonsei University Dental Hospital (Seoul, Korea) for retention follow-up between October 2020 and February 2021 (Fig. 1).

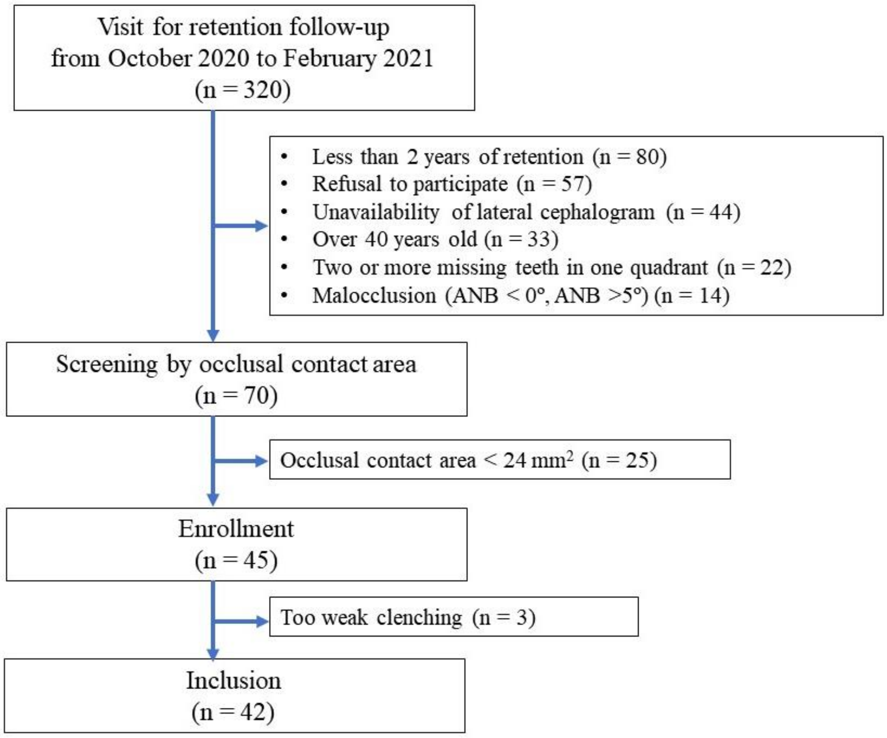


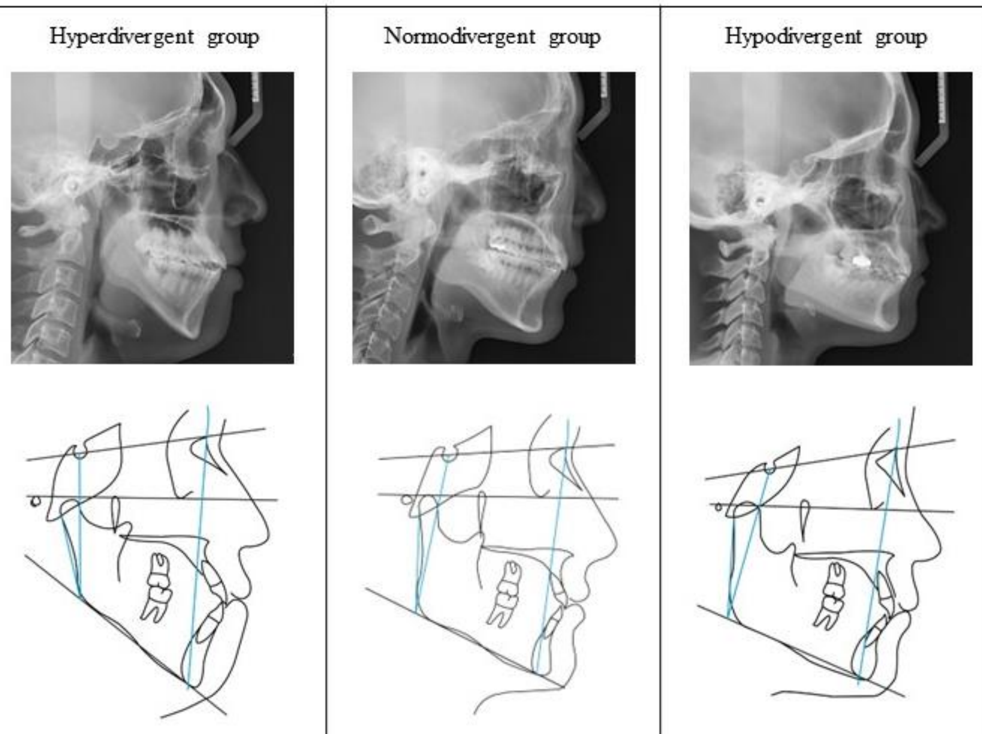
Fig. 1 Study flow chart

The inclusion criteria were as follows (Table 1): age between 18 and 40 years; OCA of more than 24 mm^2, which is the average OCA observed in the normal occlusion group, as measured in previous studies using the same methods (Yoon et al., 2010); normal occlusion with at least 6 teeth per quadrant, 0–4 mm of overjet and overbite, Class I canine and molar relationships, and no crossbite; normal craniofacial morphology in terms of sagittal and transverse dimension, which was ANB between 0° and 5° and symmetric face with less than 2 mm of menton deviation; more than two years of retention after orthodontic treatment; and availability of lateral cephalometric radiograph taken at 2-year retention. The exclusion criteria were as follows (Table 1): two or more missing teeth in one quadrant; history of craniofacial surgery; the presence of parafunction or temporomandibular disorders; systemic disease including craniofacial deformity and muscle disorder; the presence of skin allergy to the electrode; and unwillingness to remove makeup or shave for electrode bonding. The presence of parafunction, such as sleep/awake bruxism and clenching, was evaluated by self-report and clinical examination by experts. The presence of TMD was evaluated based on diagnostic criteria-TMDs (Schiffman et al., 2014). The participants enrolled in this study had malocclusion such as crowding (n = 17), protrusion (n = 12), spacing (n = 5), deep bite (n = 5), and open bite (n = 3) before orthodontic treatment, while no skeletal malocclusion such as mandibular protrusion or asymmetry was observed. All participants had fixed retainers on their maxillary and mandibular anterior teeth.

Table 1. Participants inclusion and exclusion criteria in this study

Inclusion criteria	Exclusion criteria
18<age<40	two or more missing teeth in one quadrant
OCA>24mm^2	history of craniofacial surgery
at least 6 teeth per quadrant	systemic disease including craniofacial deformity and muscle disorder
0–4 mm of overjet and overbite	skin allergy to the electrode
Class I canine and molar relationships	unwillingness to remove makeup or shave
no crossbite	parafunction: bruxism and clenching
0°<ANB< 5°	Temporomandibular disorders
less than 2 mm of menton deviation	
retention period > 2 years	
cephalometric radiograph taken at 2-year retention	

The mandibular plane angle was used to divide into three groups. The mandibular plane angle was measured as the angle formed between the mandibular plane (Go-Me) and the sella-nasion (SN) line, and it is an important parameter to define the vertical craniofacial morphology and growth pattern of the mandible (Choy, 1964). The participants were classified into the hypodivergent (less than 32°), normodivergent (from 32° to 37°), and hyperdivergent (more than 37°) groups (Fig. 2) (Knigge et al., 2021). Based on previous studies (Ueda et al., 1998; Ueda et al., 2000), the minimal sample size required to investigate the correlation of masticatory function with craniofacial morphology was calculated to be at least 29 patients. This was determined using the G-power program (G* Power 3.1.9.4, Dusseldorf, Germany) with a significance level of 0.05 and power of 80%. Furthermore, when conducting a power analysis to compare three vertical groups, a minimum of 42 participants was required. This was calculated with an effect size of 0.5, power of 0.8, and significance level of 0.05(Faul et al., 2009; Faul et al., 2007).



Hyperdivergent group		Normodivergent group		Hypodivergent group	
Facial height ratio (%)	56.9	Facial height ratio (%)	66.2	Facial height ratio (%)	77.3
Gonial angle (°)	129.6	Gonial angle (°)	123.7	Gonial angle (°)	112.5
Ramus height (㎜)	40.5	Ramus height (㎜)	51.3	Ramus height (㎜)	67.0
Mandibular plane angle (°)	42.3	Mandibular plane angle (°)	35.7	Mandibular plane angle (°)	21.6

Fig. 2 Vertical cephalometric measurements of the three groups

2. Masticatory function

In this study, the masticatory function was assessed using MMA, occlusal function, and masticatory muscle efficiency (MME). The MMA was measured in the masseter and anterior temporalis during maximum voluntary clenching (MVC) using sEMG (BioEMG III electromyographic amplifier, Bioresearch Inc., Milwaukee, WI, USA). Disposable bipolar surface electrodes were placed over the muscular bellies parallel to the muscle fibers, and a ground electrode was placed over the forehead (Ferrario et al., 2000). Before electrode placement, the skin of each participant was cleansed with alcohol to eliminate any resistance between the electrodes and the skin (Tecco et al., 2007). The participants were instructed to sit straight with the Frankfurt plane parallel to the ground and close their jaws in centric occlusion as forcefully as possible three times for 3–5 seconds each to record the sEMG value during MVC. The data of MMA were obtained using the arithmetic mean of the three repetitions. Regarding reproducibility of the measurements, intraclass correlation coefficients for three repetition of MMA was 0.923, indicating excellent reliability. The sEMG activity of the two muscle pairs was measured using the BioPAK program (Bio-Research Associates, Inc, Milwaukee, WI, USA), and the sum of the right and left sides was calculated.

The occlusal function was defined as OCA and OF in the present study, which were measured using occlusal pressure mapping system (Dental Prescale II) (Huang et al., 2022; Kwon et al., 2022; Yoon et al., 2010; Yoon et al., 2017). In the system, a thin pressure-sensitive sheet containing a grid of microcapsules filled with chromophoric substances was used to cover the occlusal surfaces entirely. When pressure was applied to the sensor sheet, the microcapsules were ruptured to release the chromogenic substance. The participants were instructed to bite the sheet with MVC for 5 seconds. By scanning the sheet using an analyzing program (Occluzer analysis software, GC, Tokyo, Japan), the OCA and OF were visually expressed and estimated with a resolution of 0.1 mm^2 and 0.1 N, respectively (Fig. 3).

MME has been defined as the quantity of electrical MMA used per unit of OF (García-Morales et al., 2003). It represents the relationship between MMA and OF exerted during chewing by quantifying the amount of MMA required to generate a specific level of OF. A higher MME suggests that less MMA is necessary to produce a given amount of OF, indicating more efficient muscle function.

$$Masticatory\ muscle\ efficiency\ (MME) = \frac{Masticatory\ muscle\ activity\ (MMA)}{Occlusal\ force\ (OF)}$$

(a) (b) (c)

Fig. 3 Measurement of occlusal force and occlusal contact area. (a), clinical setting; (b), a pressure-sensitive sheet after measurement; (c), a scanned image for the pressure-sensitive film including estimated measurements.

3. Craniofacial morphology analysis

The craniofacial morphology was determined using lateral cephalograms obtained in the maximal intercuspal position at 2-year retention. A single investigator traced all lateral cephalograms using V-ceph software (ver 5.5, Osstem, Seoul, Korea). The vertical craniofacial morphology was determined by the facial height ratio, gonial angle, ramus height, and mandibular plane angle, while the sagittal craniofacial morphology was determined by ANB angle and Wits assessment (Fig. 4). With the exception of ramus height and gonial angle, the measurements might slightly fluctuate as a result of changes in mandibular position and occlusion during orthodontic treatment (Rask et al., 2021). To evaluate the method error, 10 radiographs were randomly selected, and the measurements were repeated at 1 week interval by the same investigator. The reliability between the two measurements was calculated by intraclass correlation coefficient, which was over 0.95 indicating excellent reliability for the measurements.

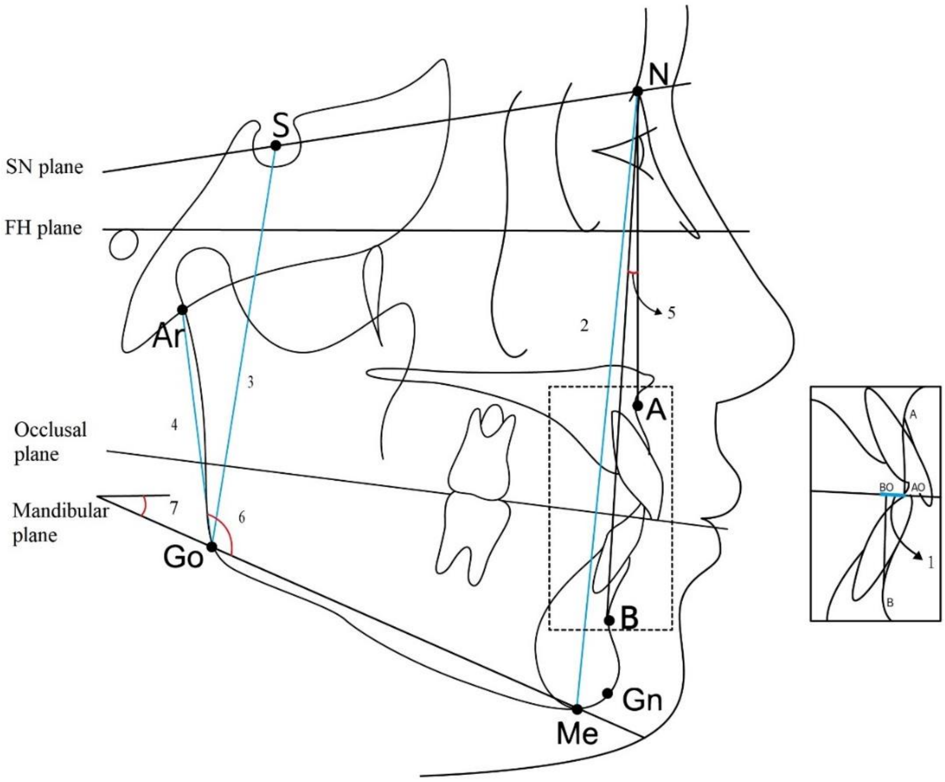


Fig. 4 Cephalometric measurements used in this study.

N, nasion; S, sella; A, A point; B, B point; Gn, gnathion; Me, menton; Ar, articulare; Go, gonion; AO and BO, perpendicular points drawn from points A and B to the functional occlusal plane, respectively.

1, Wits appraisal, the linear distance between AO and BO; 2, anterior facial height, the distance between N and Me; 3, posterior facial height, the distance between S and Go; 4, ramus height, the distance between Ar and Go; 5, ANB, A point-nasion-B point angle; 6, gonial angle, the angle formed between Ar-Go and mandibular plane; 7, mandibular plane angle, the angle formed between SN plane and mandibular plane.

4. Statistical analysis

The Kolmogorov–Smirnov test was used to confirm data normality. A one-way analysis of variance was used to compare MMA, OCA, OF, and MME among the three vertical cephalometric groups. Fisher's least significant difference was used for the post hoc test. Pearson correlations were used to assess the strength of the relationships between craniofacial morphology and masticatory function. The statistical significance level was set at $p < 0.05$, and IBM SPSS Statistics (Ver 25.0, IBM Corp., Armonk, NY, USA) was used to analyze the data.

III. Results

1. Demographic features and cephalometric measurements

This study prospectively enrolled 42 participants, including 25 women and 17 men, with a mean age of 26.9 ± 6.7 years. There was no significant difference between sexes in the participants' measurements, except for facial height ratio and ramus height (Table 2). Table 3 displays the demographic characteristics and cephalometric measurements of the participants according to the vertical cephalometric groups. MMA in the masseter and anterior temporalis and occlusal function did not show significant differences between the sexes ($p > 0.05$), although sex was not evenly distributed in each group. Therefore, the present study did not analyze the results by sex. There was no statistically significant difference in the proportion of patients who had extractions for orthodontic treatment, excluding the third molars, among the groups ($p > 0.05$). Age, retention period, ANB, Wits, and gonial angle were not significantly different among the groups ($p > 0.05$), while there were significant differences in facial height ratio, ramus height, and mandibular plane angle ($p < 0.05$).

Table 2. Differences between sexes in the measurements

	Male (n=17)	Female (n=25)	*p* value	95% CI
ANB (°)	1.90±2.46	3.45±2.41	0.079	-3.30-0.19
Wits (mm)	-3.06±4.79	-1.39±3.68	0.255	-4.59-1.26
Facial height ratio (%)	67.73±3.67	64.24±4.57	0.028*	0.40-6.58
Gonial angle (°)	123.14±8.85	121.00±7.56	0.454	-3.60-7.89
Ramus height (mm)	55.69±4.43	49.15±7.06	0.006**	2.00-11.09
Mandibular plane angle (°)	33.94±4.75	36.59±5.95	0.189	-6.67-1.37
MMA_M (μV)	305.58±192.26	295.56±204.30	0.888	-134.03-154.06
MMA_AT (μV)	263.27±116.15	304.66±157.62	0.472	-145.94-63.14
OCA (mm^2)	40.66±14.97	35.14±11.78	0.235	-3.75-14.78
OF (N)	1111.96±399.80	962.59±222.53	0.157	-60.37-359.11
OF/OCA (N/mm^2)	27.63±3.34	28.08±3.50	0.714	-2.93-2.03
MME_M (μV/N)	0.32±0.26	0.32±0.21	0.919	-0.16-0.17
MME_AT (μV/N)	0.26±0.13	0.33±0.17	0.221	-0.19-0.04

Data are presented as numbers or mean ± standard deviation. ANB, A point-nasion-B point angle; facial height ratio, the ratio of posterior to anterior facial height.

MME was calculated by dividing MMA by OF.

OCA, Occlusal contact area; OF, occlusal force; OF/OCA, occlusal force per unit occlusal contact area.

Independent Samples t-test was performed, CI indicates confidence interval.

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

Table 3. Demographic features and cephalometric measurements of each group

	Hyperdivergent (n = 15)		Normodivergent (n = 15)		Hypodivergent (n = 12)		*p* value
	Male	Female	Male	Female	Male	Female	
Sex (n)[†]	4	11	8	7	5	7	0.111
Extraction/Non-extraction (n)[†]	2/2	5/6	3/5	4/3	2/3	3/4	0.866
Age (years)	27.46 ± 6.32		27.00 ± 6.45		26.10 ± 8.13		0.895
Retention period (months)	84.92 ± 36.39		70.38 ± 37.30		70.90 ± 38.10		0.546
ANB (°)	3.93 ± 0.81		2.62 ± 1.81		2.33 ± 1.33		0.105
Wits (mm)	-0.67 ± 3.54		-2.97 ± 5.34		-2.27 ± 2.54		0.353
Facial height ratio (%)	61.17 ± 2.99[a]		65.99 ± 1.55[b]		70.16 ± 3.74[c]		0.000***
Gonial angle (°)	123.24 ± 8.01		124.07 ± 7.28		116.66 ± 7.07		0.054
Ramus height (mm)	48.39 ± 5.62[a]		50.99 ± 7.77[ab]		55.59 ± 5.84[b]		0.043*
Mandibular plane angle (°)	41.37 ± 3.09[c]		35.11 ± 1.73[b]		29.11 ± 3.53[a]		0.000***

Data are presented as numbers or mean ± standard deviation. ANB, A point-nasion-B point angle; facial height ratio, the ratio of posterior to anterior facial height.

†Chi-square test was performed, while ANOVA with Fisher LSD as a post hoc test was performed to analyze the other variables. The same superscripts indicate no significant difference between the indicated group.

* $p < 0.05$, *** $p < 0.001$, a < b < c.

2. Differences between three vertical cephalometric groups

The three vertical cephalometric groups showed statistical differences in MMA, OCA, OF, and MME (Table 4 and Fig. 5). MMA in the masseter was lower in the hypodivergent group (167.32 ± 74.92 ㎶) than that in the normodivergent group (390.42 ± 206.80 ㎶, $p < 0.05$). OCA and OF were higher in the hypodivergent group (OCA, 48.33 ± 18.27 mm^2; OF, 1261.20 ± 429.06 N) than that in the other groups (OCA, 31.92 ± 6.09 mm^2 in the hyperdivergent group and 33.32 ± 7.39 mm^2 in the normodivergent group; OF, 929.43 ± 129.50 N in the hyperdivergent group and 903.93 ± 172.26 N in the normodivergent group; $p < 0.05$). Consequently, MME in the masseter and anterior temporalis was lower in the hypodivergent group (masseter, 0.14 ± 0.06 ㎶/N; anterior temporalis, 0.18 ± 0.08 ㎶/N) than that in the other groups (masseter, 0.33 ± 0.20 ㎶/N in the hyperdivergent group and 0.44 ± 0.26 ㎶/N in the normodivergent group; anterior temporalis, 0.32 ± 0.13 ㎶/N in the hyperdivergent group and 0.38 ± 0.19 ㎶/N in the normodivergent group; $p < 0.05$).

Table 4. Comparison of the masticatory muscle activity (MMA), occlusal function, and masticatory muscle efficiency (MME) in the masseter (M) and anterior temporalis (AT) among the three vertical cephalometric groups

	Hyperdivergent (n = 15)	Normodivergent (n = 15)	Hypodivergent (n = 12)	F	*p* value
MMA_M (μV)	308.60 ± 208.25^{ab}	390.42 ± 206.80^{b}	167.32 ± 74.92^{a}	4.311	0.022*
MMA_AT (μV)	302.22 ± 135.19	339.05 ± 161.54	213.47 ± 110.20	2.359	0.110
OCA (mm^2)	31.92 ± 6.09^{a}	33.32 ± 7.39^{a}	48.33 ± 18.27^{b}	7.225	0.002**
OF (N)	929.43 ± 129.5^{a}	903.93 ± 172.26^{a}	1261.20 ± 429.06^{b}	6.419	0.004**
OF/OCA (N/mm^2)	29.53 ± 3.54	27.42 ± 3.04	26.49 ± 3.12	2.718	0.081
MME_M (μV/N)	0.33 ± 0.20^{b}	0.44 ± 0.26^{b}	0.14 ± 0.06^{a}	6.494	0.004**
MME_AT (μV/N)	0.32 ± 0.13^{b}	0.38 ± 0.19^{b}	0.18 ± 0.08^{a}	6.167	0.005**

Data are presented as mean ± standard deviation. MME was calculated by dividing MMA by OF.

OCA, Occlusal contact area; OF, occlusal force; OF/OCA, occlusal force per unit occlusal contact area.

The same subscripts indicate no significant difference between the indicated group. Fishers LSD indicates significance at 5% level when the individual group is compared with the other two groups.

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

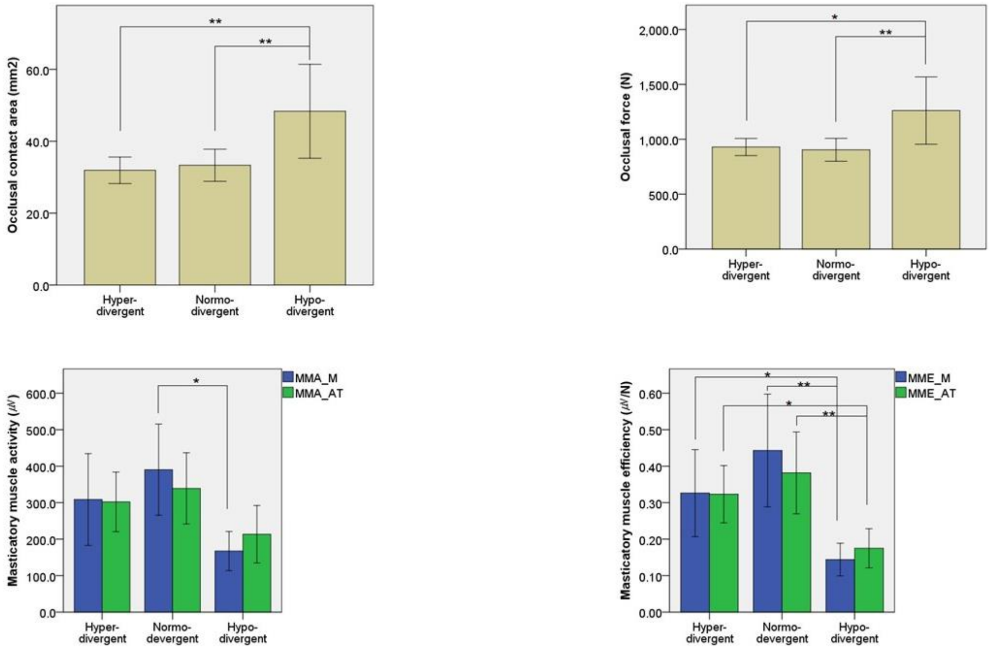


Fig. 5 Comparison of the masticatory function among the three vertical cephalometric groups. The masticatory function includes the masticatory muscle activity (MMA), occlusal force (OF), and masticatory muscle efficiency (MME).

3. Correlations of craniofacial morphology with masticatory muscle activity, occlusal function, and masticatory muscle efficiency

Vertical craniofacial morphology had a significant relationship with MMA and occlusal function (Table 5, Fig. 6). MMA in the masseter showed negative correlation with the facial height ratio (r = -0.335, p = 0.046) but positive correlation with the mandibular plane angle (r = 0.358, p = 0.032), whereas MMA in the anterior temporalis showed negative correlation with the ramus height (r = -0.364, p = 0.029). OCA and OF had positive correlation with the facial height ratio (OCA, r = 0.432, p = 0.009; OF, r = 0.399, p = 0.016) and ramus height (OCA, r = 0.335, p = 0.046; OF, r = 0.344, p = 0.040) but negative correlation with the mandibular plane angle (OCA, r = -0.422, p = 0.010; OF, r = -0.383, p = 0.021). MME also showed significant correlations with the vertical craniofacial morphology ($p < 0.05$): in the masseter, with facial height ratio (r = -0.336, p = 0.045) and mandibular plane angle (r = 0.350, p = 0.036); and in the anterior temporalis, with facial height ratio (r = -0.402, p = 0.015), ramus height (r = -0.484, p = 0.003), and mandibular plane angle (r = 0.345, p = 0.039). The sagittal cephalometric variables, ANB and Wits, were not related to any masticatory function ($p > 0.05$).

Table 5. Correlations of craniofacial morphology with masticatory muscle activity (MMA), occlusal function, and masticatory muscle efficiency (MME) in the masseter (M) and anterior temporalis (AT)

		MMA_M (μV)	MMA_AT (μV)	OCA (mm^2)	OF (N)	OF/OCA (N/mm^2)	MME_M (μV/N)	MME_AT (μV/N)
ANB (°)	r	.074	.123	-.068	-.070	.019	.027	.121
	p	.667	.473	.692	.686	.913	.875	.481
Wits (mm)	r	-.250	-.261	.025	-.015	-.133	-.312	-.280
	p	.141	.124	.884	.930	.440	.064	.098
Facial height ratio	r	-.335	-.321	.432	.399	-.325	-.336	-.402
	p	.046*	.056	.009**	.016*	.053	.045*	.015*
Gonial angle (°)	r	.159	.117	-.159	-.160	.192	.190	.172
	p	.356	.497	.354	.350	.263	.267	.316
Ramus height (mm)	r	-.169	-.364	.335	.344	-.143	-.206	-.484
	p	.324	.029*	.046*	.040*	.404	.228	.003**
Mandibular plane angle (°)	r	.358	.281	-.422	-.383	.329	.350	.345
	p	.032*	.097	.010*	.021*	.050	.036*	.039*

OCA, Occlusal contact area; OF, occlusal force; OF/OCA, occlusal force per unit occlusal contact area; ANB, A point-nasion-B point angle; Facial height ratio, the ratio of posterior to anterior facial height; r, coefficient of Pearson correlation.

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

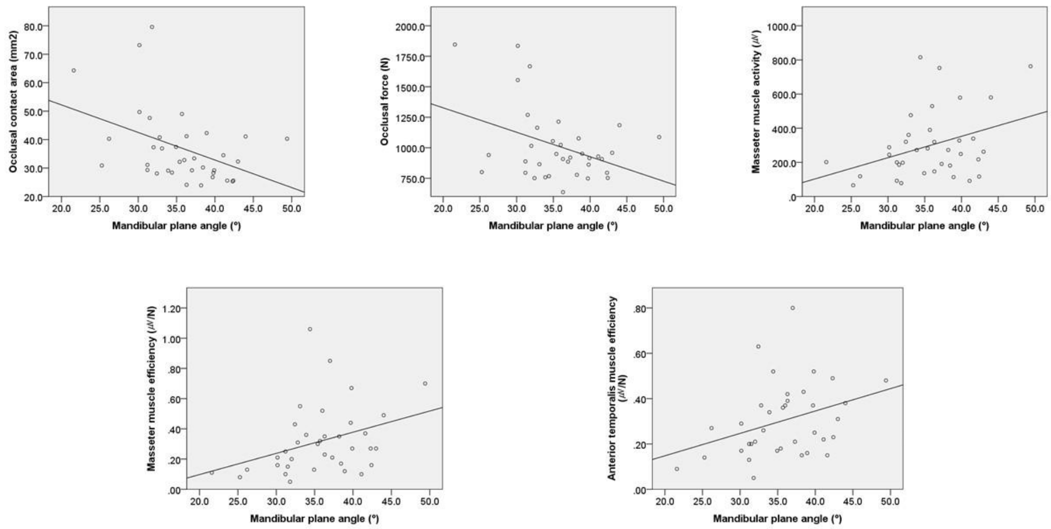


Fig. 6 Correlations of the masticatory function with mandibular plane angle. The masticatory function includes the masticatory muscle activity (MMA), occlusal force (OF), and masticatory muscle efficiency (MME). Scatterplots show the association between the mandibular plane angle and the occlusal contact area (OCA), OF, MMA_M. M, masseter; AT, anterior temporalis muscle

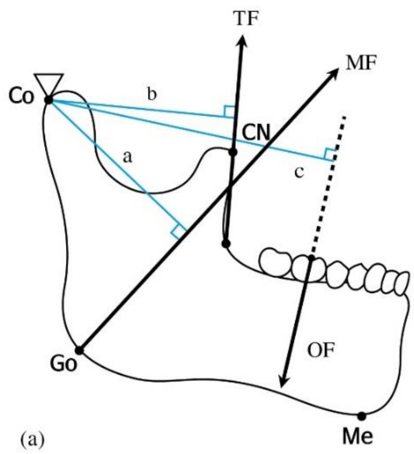
IV. Discussion

The present study investigated the relationship between craniofacial morphology and masticatory function after orthodontic treatment. Craniofacial morphology showed significant relationships with masticatory muscle activity and occlusal function, which led to the rejection of the null hypothesis. The hypodivergent group had lower masticatory muscle activity in the masseter and anterior temporalis, broader occlusal contact area, and higher occlusal force than those in the other groups. Consequently, the hypodivergent group presented the best masticatory muscle efficiency among the vertical cephalometric groups, which indicates that the masticatory function may be influenced by vertical craniofacial morphology.

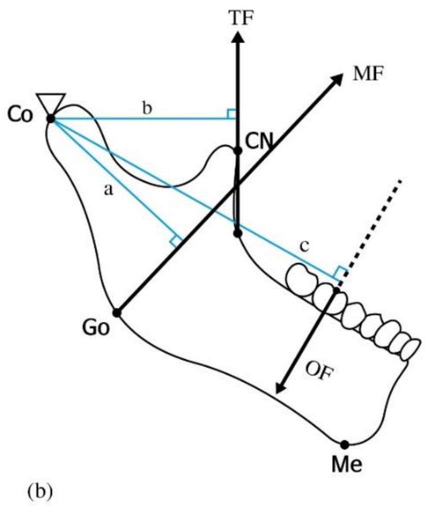
Muscle activity of the masseter was also correlated with the vertical craniofacial morphology. The hypodivergent group, which had a higher facial height ratio, low gonial angle, long ramus height, and low mandibular plane angle, showed the lowest activity, whereas the normodivergent group showed the highest activity. The activity of the masseter would be influenced by several factors, such as dynamic sensitivity of the periodontal receptors organized by occlusal function and fiber type composition of the muscles (Bakke, 2006). When the occlusal force reaches its maximum level during clenching, the periodontal receptors can reduce muscle activity, decreasing the stress on the teeth, periodontal tissue, and temporomandibular joint (Lobbezoo et al., 2001; Wang et al., 2013). The fiber type composition can be another factor that influences the activity (Farella et al., 2002). Participants with hypodivergent profiles have a predominance of slow-contracting type I fibers (Al-Farra et al., 2001). As the fibers generate action potentials with delayed depolarization, the activity of the masseter at maximum clenching may be minimal in the hypodivergent group, whereas resting metabolic activity may be significantly high.

Moreover, the increased resting metabolic rate may lead the mandible to develop horizontally and be under significantly more amount of stress (Al-Farra et al., 2001). Although high muscle activity was observed among the participants with a hypodivergent profile (Ueda et al., 1998), the masticatory performance would be different as the activity was measured through daytime observation. The activity of the temporalis muscle exhibited a similar pattern, although there were no statistical differences among the groups. As the anterior temporalis muscle mostly engages in mandibular position and differs from the masseter muscle in fiber type composition (Bakke, 1993; Farella et al., 2002), the activity at maximum clenching of the temporalis might not be the same as that of the masseter.

The occlusal function also differed according to the vertical craniofacial morphology, showing linear correlations with facial height ratio, ramus height, and mandibular plane angle. The participants in the hypodivergent group showed broad OCA and high OF as previously reported (Gomes et al., 2010; Sathyanarayana et al., 2012). It can be explained by the lever model of mandibular mechanics, which demonstrates that the mechanical advantage of the muscles gets better when the gonial angle decreases and the ramus of the mandible is in an upright position (Fig.7) (Throckmorton et al., 1980). Additionally, the thickness and cross-sectional area of the masticatory muscle would influence the occlusal function (Kubota et al., 1998; Schantz et al., 1983; van Spronsen et al., 1992). The masticatory muscles in hypodivergent participants tended to be thick (Kubota et al., 1998) and exhibit larger cross-sectional areas (van Spronsen et al., 1992), which exert more isometric strength. The hypodivergent group had considerably greater occlusal function than the other groups, suggesting an increased risk of tooth wear and prosthesis breakage (Kiliaridis et al., 1995).



(a)



(b)

Fig. 7 Mandibular lever model of the hypodivergent group (a) and hyperdivergent group (b). Please note that the mechanical advantage of a muscle is determined as the ratio of the muscle's moment arm to the moment arm of the occlusal force. Therefore, the hypodivergent group has better mechanical advantage than the hyperdivergent group.

CN, Tip of the coronoid process; Co, condyle and fulcrum; Go, gonion; Me, menton; OF, occlusal force vector; MF, muscle force vector of the masseter; TF, muscle force vector of the temporalis; a, moment arm of the masseter; b, moment arm of the temporalis; c, moment arm of the occlusal force.

Occlusion has been considered to affect MMA (Ferrario et al., 2002; Wang et al., 2010). Previous studies on MMA and craniofacial morphology were controversial (Cha et al., 2007; Gomes et al., 2010; Tecco et al., 2007); this might be due to a lack of an adequate control group and the ambiguity of the criteria for normal occlusion. Since normal occlusion was determined based on the molar relationship rather than the function (Sathyanarayana et al., 2012; Ueda et al., 1998), the individuals' occlusal status may have affected the results of previous investigations. In this study, the mean OCA and OF values of the 42 participants were 36.98 ± 12.98 mm^2 and 1012.38 ± 296.44 N, respectively; these are relatively high compared with those reported in previous studies, in which the same parameters were measured with the same equipment for participants with normal occlusion

(Kitafusa, 2004; Yoon et al., 2010). All 42 participants exhibited normal overjet and overbite, as well as Class I canine and molar relationships. Since occlusal function improved throughout the retention period rather than immediately after orthodontic treatment (Dinçer et al., 2003; Yoon et al., 2017), it can be considered that the participants in this study, who had a retention period of two years or more, had individually stabilized and maximized occlusion under their skeletal relationship.

MME revealed significant differences among the groups. The efficiency in the masseter and anterior temporalis was the best in the hypodivergent group and positively correlated with the mandibular plane angle. This suggests that individuals with lower mandibular plane angles require lesser muscle activity to attain the same OF at maximum clenching. When MMA is constant, MME improves as the occlusal function improves. Therefore, practitioners should attempt to obtain the maximum level of occlusal contact by restorative, prosthetic, or orthodontic treatment.

The masticatory function may differ depending on the anteroposterior craniofacial morphology or during various jaw functions. This study included participants with normal craniofacial morphology measured by sagittal and transverse dimensions, as other craniofacial parameters except the vertical parameters were barely related to the masticatory function (Miralles et al., 1991; Tecco et al., 2007). Changes in occlusal stability and mandibular position during jaw function may affect MMA (Wang et al., 2010). MVC represents the static performance of the masticatory function since it exhibits high reproducibility and consistency (Castroflorio et al., 2006). Moreover, MVC would be appropriate to investigate the masticatory function, including the occlusal function. Although this study examined MMA during different static and dynamic performances, such as mouth opening, rest, swallowing, speaking, and MVC, there were no statistical differences among the groups except in MVC.

This study presents an integrated approach to defining normal occlusion, taking into account both morphological and functional aspects. Our focus on post-orthodontic treatment patients offers a unique perspective. Importantly, this study reports novel findings that individuals with a hypodivergent profile exhibit lower MMA but higher MME values due to their broader occlusal contact area and enhanced biting force. There were some limitations to this study. Due to the noninvasive nature of sEMG, MMA could not be assessed directly (Nishi et al., 2016), and connective tissue and fat with low electrical conductivity could have altered the sEMG signal (De la Barrera and Milner, 1994; van der Glas et al., 1996). Moreover, the sEMG signal may differ depending on the thickness and orientation of the masticatory muscles as well as body size, overall health, and nutritional status (Gaszynska et al., 2017). Longitudinal studies assessing the masticatory function before and after orthodontic treatment with a larger sample size may demonstrate changes in the masticatory function induced by occlusal changes.

V. Conclusion

1. The null hypothesis was rejected.
2. Vertical craniofacial morphology is related to masticatory function in participants with normal occlusion after orthodontic treatment.
3. Participants with hypodivergent facial profiles may have a greater occlusal function with lesser masticatory muscle activity and consequently greater masticatory muscle efficiency compared with participants with hyper- and normodivergent profiles.

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국문요약

두개안면 형태와 저작근 활성도 및 교합기능과의 상관관계

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치의학과

윤 유 정

저작 기능은 두개 안면 형태와 관련이 있다고 알려져 있다. 저작기능은 저작근 활성과 교합 기능으로 평가할 수 있다. 이번 연구는 교정치료를 종료한 지 최소 2 년이상 경과하여 안정적인 교합을 이루는 환자들 에서 두개 안면형태와 저작기능 사이의 관계를 알아보고자 한다.

2020년 10월부터 2021년 2월까지 연세대학교 치과병원 교정과에 방문한 환자들 중에 교합면적이 24 mm^2이상을 보이며 결손치가 없는 40세 미만의 환자 42명을 후향적으로 연구하였다. 하악 평면각에 따라 Hyperdivergent, Normodivergent, Hypodivergent 세 군으로 나누어 연구를 진행하였다. 저작근 활성(MMA)은 교근과 전방 측두근에서 surface electromyography를 이용하여 측정하였다. 이번연구에서 교합기능은 교합접촉면적(OCA)와 교합력(OF)으로 정의하였으며, occlusal pressure mapping system을 사용하여 평가하였다. 저작근 효율(MME)는 저작근 활성을 교합력으로 나눈 값으로 정의하였다. 두개 안면 형태는 측모두부방사선사진 계측을 통하여 분석하였다. 저작 기능은 일원분산분석(one-way analysis of variance)을 통해 세 그룹간 차이를 비교하였다. 두개안면 형태와 저작기능 간의 관계는 피어슨 상관분석(Pearson correlation)을 통해 분석하였다.

Hypodivergent그룹은 교근에서 가장 낮은 저작근 활성(167.32 ± 74.92 μV)을 보였고, 교근과 전방 측두근에서 가장 높은 저작근 효율을 보였다 (0.14 ± 0.06 μV/N, 0.18 ± 0.08 μV/N, $p < 0.05$). 교근에서 저작근 활성은 하악 평면각과 양의 상관관계를 보였고 (r = 0.358), 반면에 교합접촉면적(r = -0.422) 과 교합력(r = -0.383)은 음의 상관관계를 나타냈다 ($p < 0.05$). 전방 측두근은 ramus height과 음의 상관관계를 보였다 (r = -0.364, $p < 0.05$).

수직적인 두개 안면형태는 저작기능과 상관관계가 있다. 특히 Hypodivergent한 형태의 안모에서는 낮은 저작근 활성과 높은 교합기능을 보여 결과적으로 우수한 저작근 효율을 나타냈다. 이러한 결과는 임상치료에 있어, Hypodivergent한 형태의 환자에게 보다 세심한 교정진단과 보철치료 계획이 수립되어야 함을 의미한다.

핵심이 되는 말 : 두개안면 형태, 저작기능, 저작근 활성, 교합기능