Clinical Oral Investigations (2023) 27:5367–5376
https://doi.org/10.1007/s00784-023-05156-2

RESEARCH

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

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Received: 8 January 2023 / Accepted: 11 July 2023 / Published online: 19 July 2023

Abstract

Objectives 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.

Materials and Methods Fourty-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.

Results The hypodivergent group had the lowest MMAand the highest MME in the masseter (167.32 ± 74.92 µV and 0.14 ± 0.06 µV/N, respectively) and anterior temporalis muscles (0.18 ± 0.08 µV/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, $p < 0.05$).

Conclusions Vertical craniofacial morphology was related to masticatory function. Hypodivergent individuals may have low MMA and high occlusal function, resulting in good masticatory muscle efficiency.

Clinical relevance Hypodivergent individuals require careful consideration in orthodontic diagnosis and prosthetic treatment planning.

Keywords Craniofacial morphology · Masticatory function · Masticatory muscle activity · Occlusal function

Introduction

Several articles have reported the relationship between morphology and function in the craniofacial region. Since Moss and Salentijin [1] 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 [2]. 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 [3, 4].

Surface electromyography (sEMG) and occlusal pressure mapping system have been widely used to assess MMA and

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occlusal function, respectively [5, 6]. 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 [7]. sEMG can evaluate masticatory muscle function in a simple and noninvasive manner by detecting the muscle activity from the skin above the muscle [5]. Previous studies using sEMG have reported the relationship between craniofacial morphology and masticatory function [8–12] with the daytime MMA showing a correlation with the vertical craniofacial morphology [8]. 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 [6, 13, 14]. 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 [15].

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 [8–12]. 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 [13]. 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 [16, 17], there appears to be a paucity of studies that consider both MMA and occlusal funciton 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 [9–11]. Orthodontic treatment can improve occlusal function by achieving stable occlusion under the craniofacial morphology [18]. Furthermore, it is generally known that occlusal function improves over time rather than immediately after orthodontic treatment [6, 19]. 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 [20]. In conducting this study, we tested the null hypothesis that there is no relation between craniofacial morphology and masticatory function.

Materials & methods

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).

The inclusion criteria were as follows: 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 [20]; 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: 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 [21]. 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

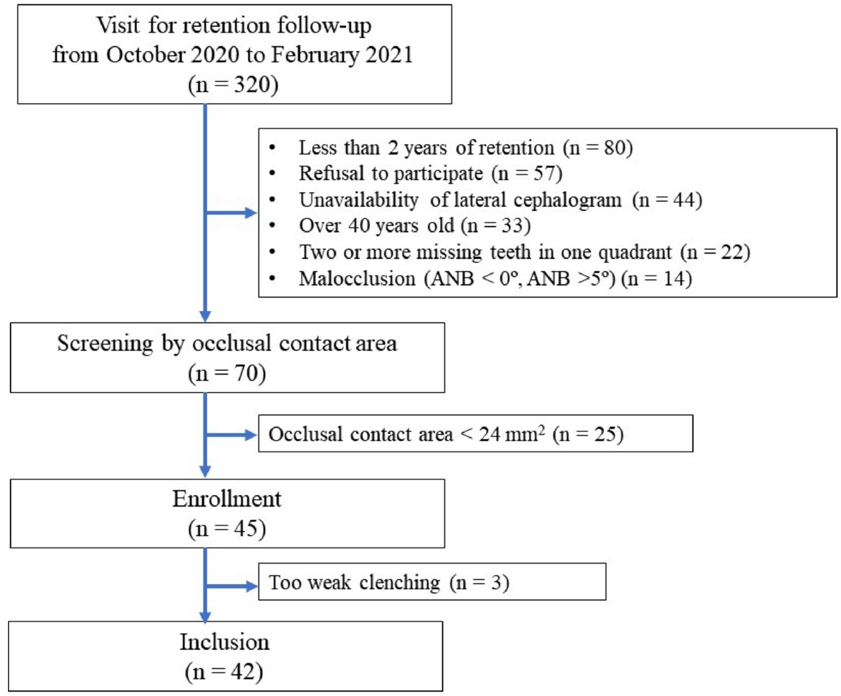

Fig. 1 Study flow chart

asymmetry was observed. All participants had fixed retainers on their maxillary and mandibular anterior teeth.

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 [22]. The participants were classified into the hypodivergent (less than 32°), normodivergent (from 32° to 37°), and hyperdivergent (more than 37°) groups (Fig. 2) [23]. Based on previous studies [8, 24], 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 [25, 26].

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 [27]. Before electrode placement, the skin of each participant was cleansed with alcohol to eliminate any resistance between the electrodes and the skin [12]. 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 s 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) [6, 13, 14, 20]. 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 s. 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 (Supplement Fig. 3).

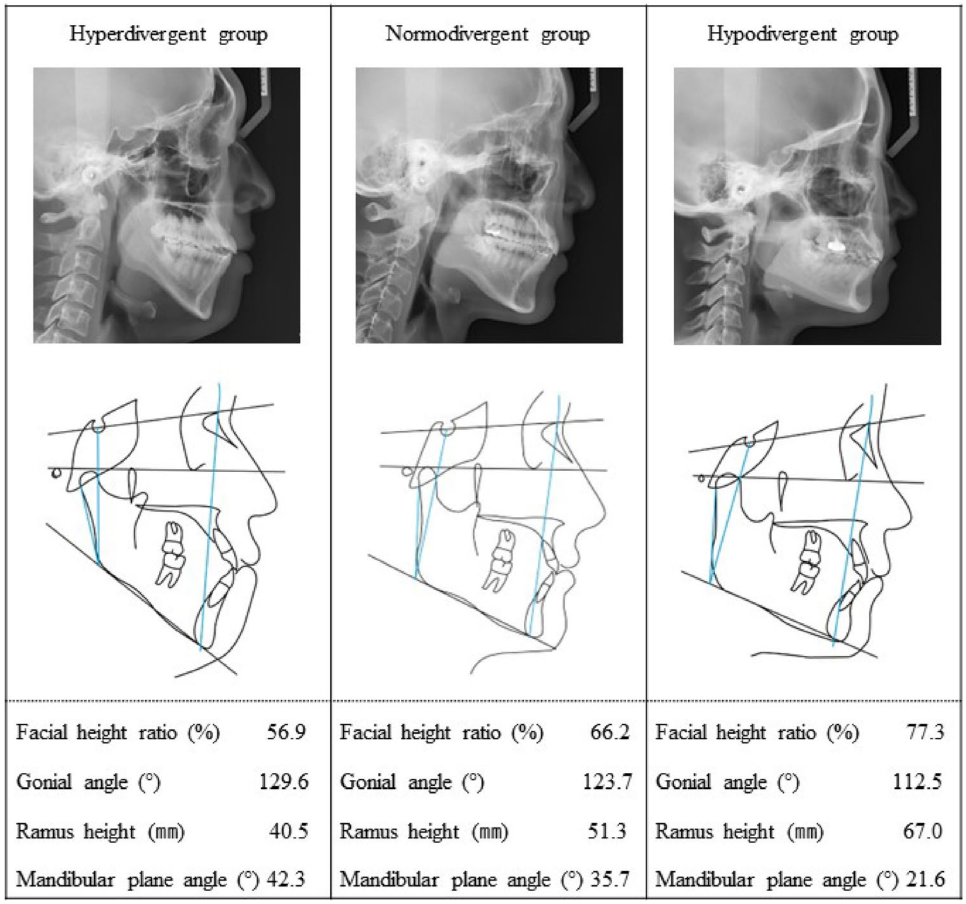

Fig. 2 Vertical cephalometric measurements of the three groups

MME has been defined as the quantity of electrical MMA used per unit of OF [28]. 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.

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

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 (Supplement Fig. 1). 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 [29]. 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.

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.

Results

This study prospectively enrolled 42 participants, including 25 women and 17 men, with a mean age of 26.9 ± 6.7 years. Table 1 displays the demographic characteristics and

Table 1 Demographic features and cephalometric measurements of each group

	Hyperdivergent ($n=15$) Male Female	Normodivergent ($n=15$) Male Female	Hypodivergent ($n=12$) Male Female	p value
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

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 ($p<0.05$).

The three vertical cephalometric groups showed statistical differences in MMA, OCA, OF, and MME (Table 2 and Fig. 3A). MMA in the masseter was lower in the hypodivergent group (167.32 ± 74.92 μV) than that in the normodivergent group (390.42 ± 206.80 μV, $p<0.05$). 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 μV/N; anterior temporalis, 0.18 ± 0.08 μV/N) than that in the other groups (masseter, 0.33 ± 0.20 μV/N in the hyperdivergent group and 0.44 ± 0.26 μV/N in the normodivergent group; anterior temporalis, 0.32 ± 0.13 μV/N

Table 2 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 ± 129.50[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

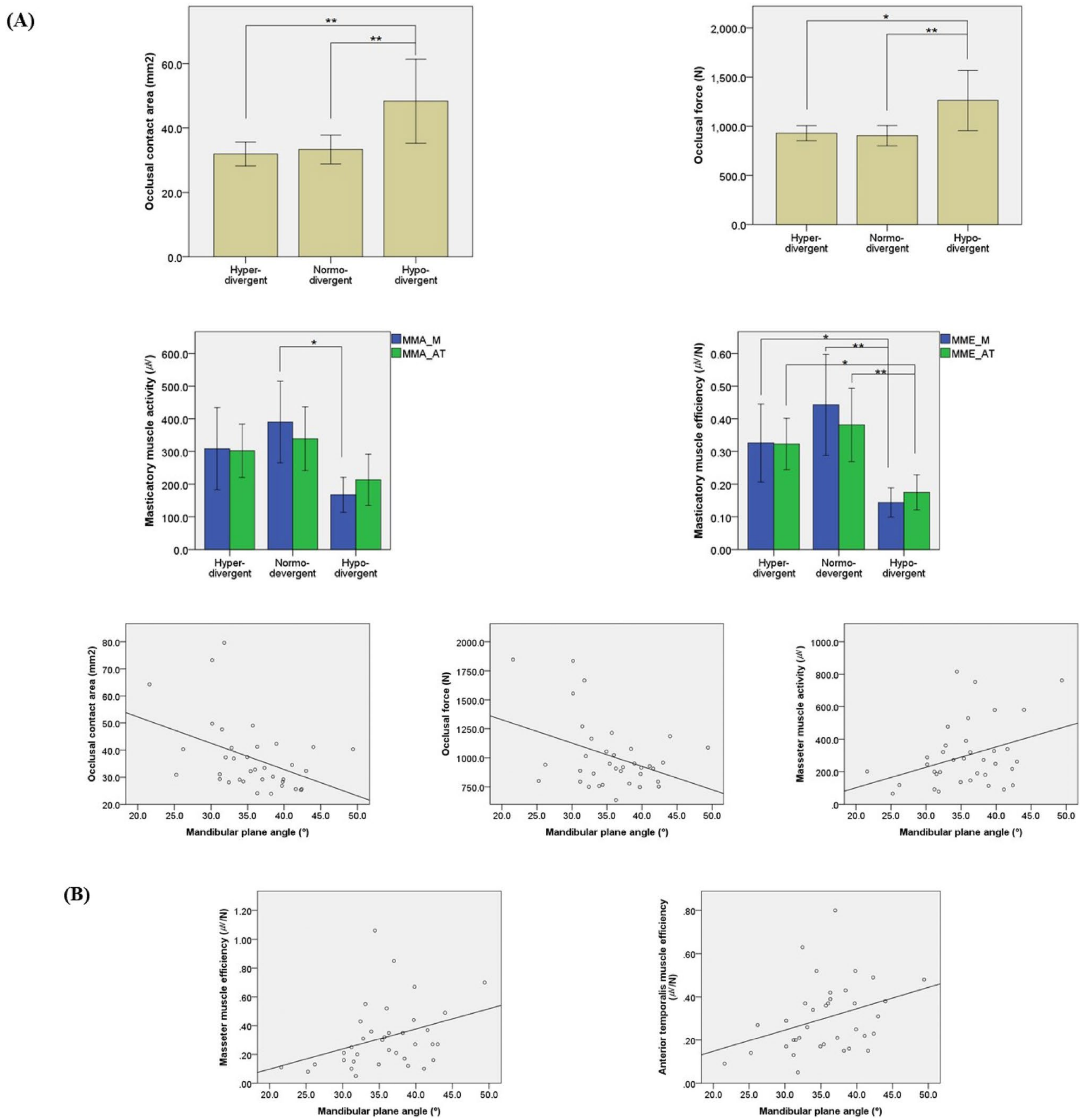

Fig. 3 Comparison of the masticatory function among the three vertical cephalometric groups (**A**) and correlations of the masticatory function with mandibular plane angle (**B**). The masticatory function includes the masticatory muscle activity (MMA), occlusal force (OF), and masticatory muscle efficiency (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

in the hyperdivergent group and 0.38 ± 0.19 μV/N in the normodivergent group; $p < 0.05$).

Vertical craniofacial morphology had a significant relationship with MMA and occlusal function (Table 3, Fig. 3B). 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 ($p > 0.05$).

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 [30]. 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 [31, 32]. The fiber type composition can be another factor that influences the activity [33]. Participants with hypodivergent profiles have a predominance of slow-contracting type I fibers [34]. 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 [34]. Although high muscle activity was observed among the participants with a hypodivergent profile [8], 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 [33, 35], the activity at maximum clenching of the temporalis might not be the same as that of the masseter.

Table 3 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 value	.667	.473	.692	.686	.913	.875	.481
Wits (mm)	r	–.250	–.261	.025	–.015	–.133	–.312	–.280
	p value	.141	.124	.884	.930	.440	.064	.098
Facial height ratio	r	–.335	–.321	.432	.399	–.325	–.336	–.402
	p value	.046*	.056	.009**	.016*	.053	.045*	.015*
Gonial angle (°)	r	.159	.117	–.159	–.160	.192	.190	.172
	p value	.356	.497	.354	.350	.263	.267	.316
Ramus height (mm)	r	–.169	–.364	.335	.344	–.143	–.206	–.484
	p value	.324	.029*	.046*	.040*	.404	.228	.003**
Mandibular plane angle (°)	r	.358	.281	–.422	–.383	.329	.350	.345
	p value	.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

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

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 [9, 36]. 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 (Supplement Fig. 2) [37]. Additionally, the thickness and cross-sectional area of the masticatory muscle would influence the occlusal function [38–40]. The masticatory muscles in hypodivergent participants tended to be thick [38] and exhibit larger cross-sectional areas [40], 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 [41].

Occlusion has been considered to affect MMA [16, 17]. Previous studies on MMA and craniofacial morphology were controversial [9, 11, 12]; 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 [8, 36], 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 [20, 42]. 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 [6, 19], 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 [12, 43]. Changes in occlusal stability and mandibular position during jaw function may affect MMA [16]. MVC represents the static performance of the masticatory function since it exhibits high reproducibility and consistency [44]. 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 [45], and connective tissue and fat with low electrical conductivity could have altered the sEMG signal [46, 47]. 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 [48]. 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.

Conclusion

- The null hypothesis was rejected.
- Vertical craniofacial morphology is related to masticatory function in participants with normal occlusion after orthodontic treatment.
- 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.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00784-023-05156-2.

Author contribution • Data collection: Yu Jung Yoon, Ju-Young Kang, and Yoon Jeong Choi

• Data analysis and visualization: Yu Jung Yoon, Ju-Young Kang, Kyung-Ho Kim, Jung-Yul Cha, and Yoon Jeong Choi

• Writing—original draft: Yu Jung Yoon and Ju-Young Kang
• Writing – review & editing: Kyung-Ho Kim, Jung-Yul Cha, Hyung Joon Ahn, and Yoon Jeong Choi

Funding This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. NRF-2020R1F1A1069316).

Declarations

Ethics approval and consent to participate 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.

Conflict of interest All authors have no financial disclosures or conflicts of interest to declare.

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