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Musculomandibular morphology in individuals with different vertical skeletal growth patterns: an MRI and cone beam computed tomography study

Katrina Gardovska[1], Ilga Urtane[1], Gaida Krumina[2]

SUMMARY

Objective. The aim of this study was to analyse the volumetric and crossectional parameters of masseter and medial pterygoid muscles in the relation with mandibular skeletal morphology in individuals with different underlying growth patterns in the vertical dimension.

Material and methods. The study originally involved 76 individuals with definite clinical and radiological criteria: 31 skeletal Class III and 26 skeletal Class II patients before the orthognathic surgery and 20 skeletal class I (normal) individuals with complaints of wisdom teeth and associated medical problems. On the basis of cephalometric measurement of the mandibular plane and sella-nasion (MP-SN), the study sample was categorised according to the vertical facial dimension in 3 different growth pattern subgroups: 19 subjects with horizontal growth pattern, 25 subjects with vertical growth pattern and 33 subjects with neutral growth pattern. MRI was performed for the masseter and medial pterygoid muscles, and volume and cross-sectional area measurements were performed. Cone beam computed tomography (CBCT) investigation was performed for the assessment of craniofacial structures and the following measurements of the mandibular parameters were obtained: height of ramus, length of mandibular corpus, overall mandibular length, inter-angular width and intercondylar width.

Results. There were statistically significant differences among all study groups regarding masseter volume ($p<0.006$) and CSA ($p<0.006$), with the highest values in the horizontal growth pattern group and the lowest values in vertical growth pattern group. After Bonferroni correction, statistically significant difference ($p<0.004$ and $p<0.008$) was noted between the horizontal and vertical growth pattern groups, respectively. A similar tendency was observed for the medial pterygoid, but with no statistical significance. A statistically significant negative correlation was observed between MP-SN and the volume of masseter and medial pterygoid in the overall sample. Of the seven muscular and mandibular variables included in the regression analysis, the final model included only four variables that were significantly associated with MP-SN and explained 37% of its variance (masseter volume ($p=0.017$), mandibular overall length ($p<0.001$), height of mandibular ramus ($p=0.003$), and length of mandibular corpus ($p<0.001$)).

Conclusions. The masseter muscle seems to be more sensitive to the variation in mandibular morphology than the medial pterygoid muscle, and volume as the biomechanical characteristic seems to be a more significant parameter of the size of the interaction with vertical skeletal growth patterns.

Keywords: masseter, medial pterygoid, MRI, CBCT.

INTRODUCTION

Both genetics and environmental factors contribute to complex craniofacial growth and development (1). The performance of mandibular muscles creates a local biomechanical environment in this region. The hypothetical association among the morphology of mandibular muscles, the mandible and the vertical skeletal pattern is based on Wolff's law (2), the functional matrix theory of growth created by Moss (3) and the ability of muscles to restrain vertical craniofacial development (7). The mandible itself is a highly complex morphological structure composed of several independent parts. Postnatal growth of the human mandible is characterised by an extensive variation that strongly determines

[1]*Department of Orthodontics, Institute of Stomatology, Riga Stradins University, Riga, Latvia*
[2]*Institute of Radiology, Riga Stradins University, Riga, Latvia*

Address correspondence to Katrina Gardovska, Department of Orthodontics, Institute of Stomatology, Riga Stradins University, 20 Dzirciema Street, Riga, LV 1007, Latvia.
E-mail address: katrinagardovska@inbox.lv

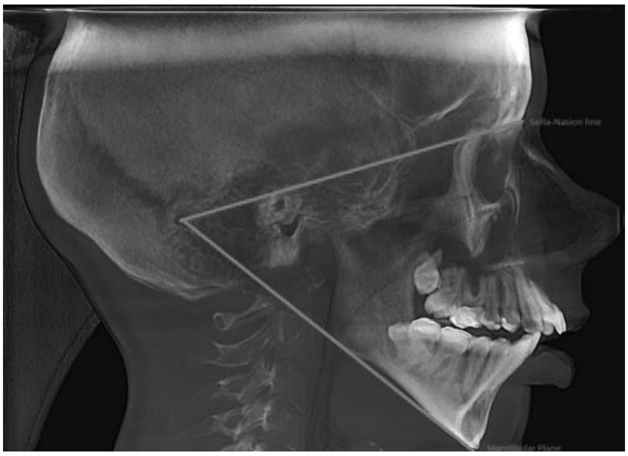

Fig. 1. MP-SN angle in the sagittal plane on CBCT image

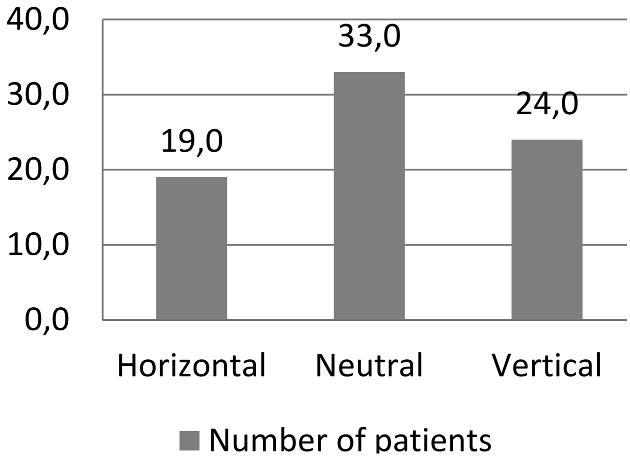

Fig. 2. Distribution of subjects in study subgroups based on MP-SN

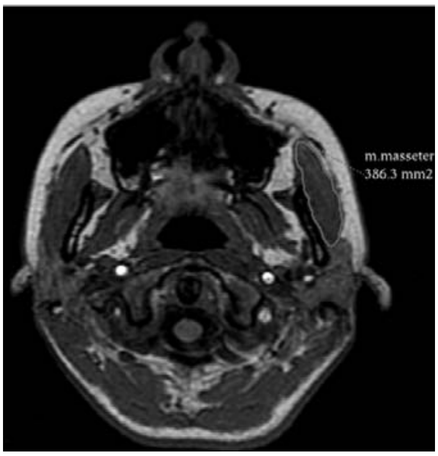

Fig. 3. Cross-sectional area of Masseter (cm²)

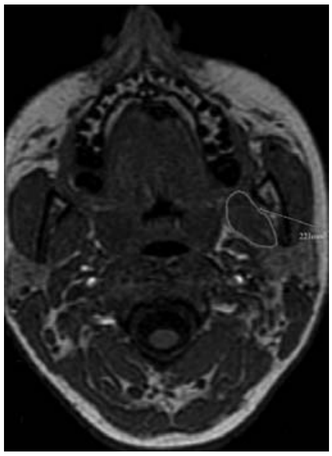

Fig. 4. Cross-sectional area of the medial pterygoid muscle (cm²)

both the vertical and sagittal dimensions of the craniofacial complex (4). The most significant growth area of the mandible is its posterior region (5, 6). On the basis of specific anatomy (origins and insertions) and physiological function as the main elevators of the mandible, the masseter and medial pterygoid muscle could be strongly associated with mandibular and craniofacial morphology, particularly in the vertical dimension. These muscles may play an important role in the aetiology of dentofacial deformities as well as influencing the long-term stability of the treatment results by their capacity of adaptation (7).

Mastication muscles can be investigated using a variety of non-invasive radiographic techniques, such as ultrasonography (US) (8, 9), computed tomography (CT) (10, 28) and magnetic resonance imaging (MRI) (11-13, 27). The cross-sectional area and volume are the size parameters of muscles, indicating maximal isometric contraction strength and loads that are used in the literature to analyse the performance and force developed by mandibular muscles.

In the literature, it is well recognized that there are three basic morphological types of dentofacial deformities in the vertical dimension. These are generally used to describe as individuals with increased vertical dimension (hyper-divergent (14), long face (15), dolichocephalic), decreased vertical dimension (hypo-divergent (14), short face (15), brachycephalic) and average or normal morphology of the face in the vertical dimension (normodivergent (15)). These are referred to as having vertical, horizontal and neutral craniofacial growth patterns, respectively.

Interactions between muscles and skeletal structures of the craniofacial region are complex, and wide controversies exist in the literature on the nature of these interactions (16) and a profound analysis of patients requiring orthognathic surgery regarding the issue would be informatively appropriate.

The objectives of the present study were to analyse masseter, medial pterygoid muscle and mandibular skeletal parameters in individuals with different underlying growth patterns in the vertical dimension; to compare muscular parameters among study groups; to evaluate the association between muscular and mandibular skeletal parameters; and to investigate the contribution of masseter and medial pterygoid muscles on the vertical dimension of the craniofacial area.

MATERIAL AND METHODS

The study originally involved 76 individuals (mean age 20.8 years; S.D.3.17) with definite clinical and radiological criteria: 31 skeletal Class III and 26 skeletal Class II patients prior to orthognathic surgery and 20 skeletal Class I (normal) individuals.

Fig. 5. Height of mandibular ramus (cm) (Co-Go)

Fig. 6. Length of mandibular corpus (cm) (Go-Gn)

Fig. 7. Length of overall mandible (Co-Gn)

The inclusion criteria were ANB angle of ≥4º for Class II, <0º for Class III and dentoalveolar Class II or III. The exclusion criteria were as follows: congenital dentofacial syndromes (including cleft lip±palate), clinically evident facial asymmetry, functional mandibular deviations, symptoms of temporomandibular disorders, rheumatoid or other types of arthritis and previous orthodontic treatment.

The measurement of the mandibular plane and sella-nasion (MP-SN) on the cone beam computed tomography (CBCT) lateral cephalometric image was used as the criteria for the assessment of the vertical facial dimension and for the assignment of individuals as having either horizontal, vertical or normal growth patterns of facial morphology. MP-SN is measured between the mandibular plane (gonion – gnathion) (17) and the cranial base SN (Fig. 1) with the mean value of 320±5 (18, 19). Thus, all 76 individuals were categorised according to the vertical facial dimension in 3 different growth pattern subgroups: 19 subjects with a horizontal growth pattern (MP-SN<270), 25 subjects with a vertical growth pattern (MP-SN>370) and 33 subjects with a neutral growth pattern (MP-SN=27-370). The distribution of patients in subgroups is illustrated in Fig. 2.

Magnetic resonance imaging (MRI) was performed for the mandibular muscles using 1.5T GE MEDICAL SYSTEMS Signa HDx. The position of the patient's head was standardized: supine with the Frankfurt horizontal plane oriented perpendicular to the floor; mouth closed with teeth together; and short, calm breathing. Scan protocol included the following: T1 SE in the sagittal plane, T2 FSE in the axial plane, STIR T2 sequence images in the coronal plane and 3D SPGR T1 with subsequent 2D and 3D image reconstructions for the assessment of muscular size parameters. The slice thickness was 2 mm, and the inter-slice gap was 2 mm, FOV24x18. The following measurements were collected for the mandibular muscles on the left and right sides: cross-sectional area (CSA) (Fig. 3), volume and longitudinal dimension for the masseter and medial pterygoid muscles (Fig. 4). The measurement of CSA was perpendicular to the long axes of muscles (20), and the maximum CSA was defined as the mean of the largest CSA and those measured in the adjacent scans (21). Volume was calculated by multiplying the sequential CSA with the slice thickness plus the inter-slice gap.

Cone-beam computed tomography (CBCT) using an iCAT scanner (iCAT Next Generation, Imaging Sciences International, Inc., Hatfield, PA, USA) was performed for the maxillofacial area for the measurement analysis of mandibular skeletal structures. The protocol was standardized with the individual seated in a chair with the following parameters of the procedure: 120 kV, 5 mA, 0.4 vox, 17 mm FOV and an exposition time of 7 s. Acquired scans were reconstructed in three planes (sagittal, coronal and axial) and analysed using examVision software (Imaging Sciences International, Inc. Hat-

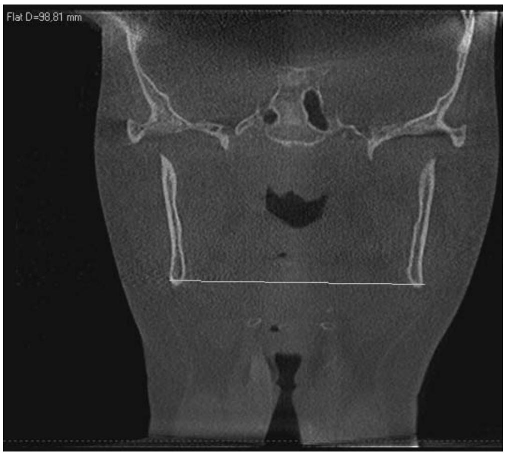

Fig. 8. Inter-angular distance (cm)

Fig. 9. Inter-condylar distance (lateral) (cm)

Fig. 10. Intercondylar distance (medial) (cm)

field, PA, ASV). The following linear measurements of the mandible were collected on the left and right sides: height of ramus (Condylus-Gonion) (Fig. 5), length of the mandibular corpus (Go-Gnathion) (Fig.6.) and overall mandibular length (Condylus-Gnathion) (Fig. 7.), and assessment of the transversal dimension, inter-angular width (distance between the most posterior and lower mandibular angulus points) (Fig.8.), and intercondylar width (Fig. 9, 10) was performed.

All the measurements of the mandible were performed twice bilaterally on the CBCT images at 2-week interval by one operator.

Statistical analyses were performed with SPSS 20.0 for Windows. The distribution of data was checked with the Kolmogorov-Smirnov test. The standard measure of error as proposed by Dahlberg was calculated, and no measurement exceeded limiting the value of 1.0. Data were analysed using descriptive statistics and one-way analysis of variance (ANOVA) with Bonferroni's correction to analyse and compare study groups, Pearson's correlation coefficients to assess the associations between muscular and mandibular skeletal variables separately in every study group and multivariate linear regression analysis to identify mandibular and muscular factors that influence the vertical dimension of the craniofacial morphology.

The study protocol was approved by the Ethics Committee of Riga Stradins University (decision accepted with the specifications in the Declaration of Helsinki).

RESULTS

There were differences between the left and right side measurements of masseter and medial pterygoid for the CSA and volume (Tables 1 and 2), but there was no consistent preference or statistical significance, and in further investigations, the left and right variables were averaged, and the mean value of both sides was used.

In the overall sample, the masseter volume showed a statistically significant positive correlation with its CSA (0.81, $p<0.000$), with the medial pterygoid volume (0.55, $p<0.000$) and CSA (0.57, $p<0.000$), and a correlation between the medial pterygoid volume and CSA (0.47, $p<0.000$). The MP-SN angle showed a statistically significant negative correlation with the masseter volume (-0.44, $p<0.000$), masseter CSA (-0.41, $p<0.000$) and medial pterygoid volume (-0.29, $p<0.01$) in the overall sample.

Descriptive statistics of the masseter; medial pterygoid muscle; and mandibular variables of neutral, horizontal and vertical growth pattern groups are presented in Tables 3, 4 and 5, respectively.

Table 1. Average distance between anatomical apex and apical foramen

Volume (cm^3)	Neutral growth pattern		Horizontal growth pattern		Vertical growth pattern	
	Mean	SD	Mean	SD	Mean	SD
Mas right	21.7	5.52	24.9	6.19	19.7	4.79
Mas left	22.4	5.61	25.1	6.37	19.4	4.56
MPM right	10.0	3.12	11.1	3.56	10.3	4.77
MPM left	10.2	3.07	11.6	3.67	10.6	4.87

MPM – medial pterygoid muscle; Mas – masseter.

Table 2. Measurements of the masseter and medial pterygoid muscle CSA from the left and right sides

CSA (mm2)	Neutral growth pattern		Horizontal growth pattern		Vertical growth pattern	
	Mean	SD	Mean	SD	Mean	SD
Mas right	465.4	102.79	508.6	77.61	426.2	79.79
Mas left	475.0	110.37	52.7	81.90	431.1	79.59
MPM right	285.7	59.04	302.7	69.79	275.6	77.25
MPM left	294.9	65.42	313.5	67.17	291.1	89.12

MPM – medial pterygoid muscle; Mas – masseter.

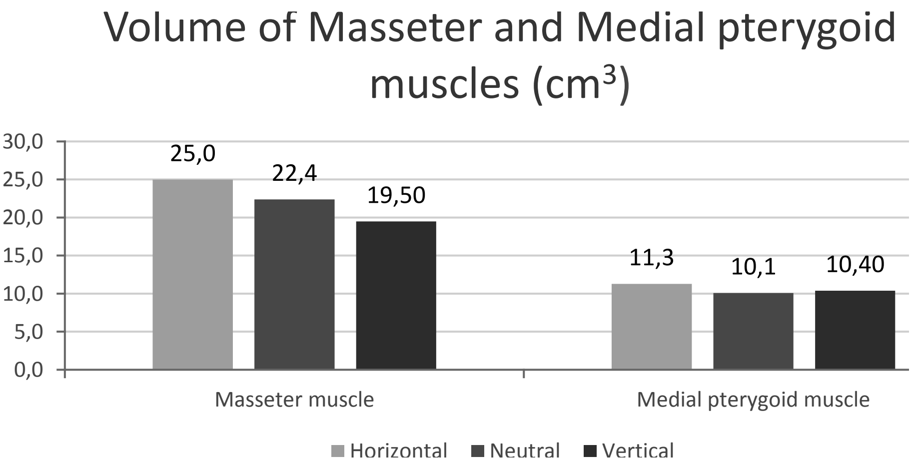

Fig. 11. Comparison of the mean values of volume of the masseter and medial pterygoid muscles among the different growth pattern groups

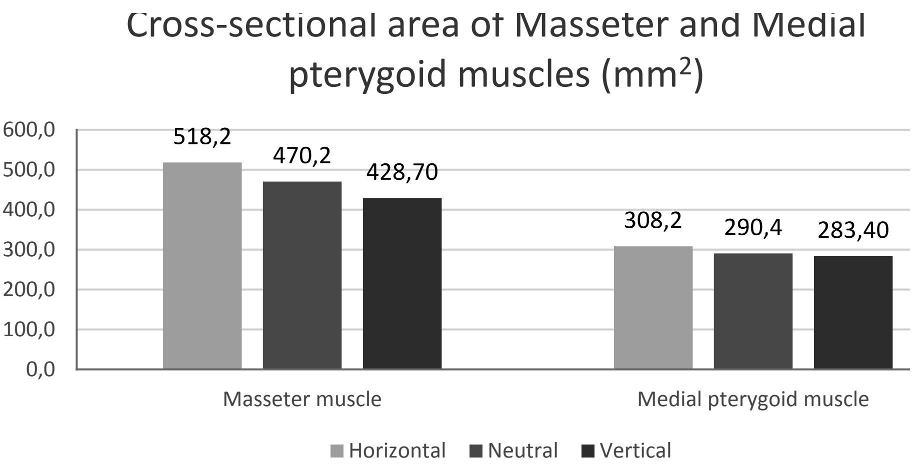

Fig. 12. Comparison of the mean values of CSA of the masseter and medial pterygoid muscle among the different growth pattern groups

The comparison among different growth pattern groups of the masseter and medial pterygoid muscle CSA and volume are presented in Figures 11 and 12.

There were statistically significant differences among all study groups of the masseter volume ($p<0.006$) and CSA ($p<0.006$), with the highest values in the horizontal growth pattern group and the lowest values in the vertical growth pattern group (Fig. 6 and 7). After Bonferroni's correction, there was statistically significant difference ($p< 0.004$ and $p<0.008$) between horizontal and vertical growth type groups.

A similar tendency was observed for the variables of the medial pterygoid muscle to be larger in the horizontal growth pattern group, but with no statistical significance.

Correlations between muscular and mandibular parameters were calculated in every study group separately and are presented in Tables 5-8.

Table 3. Descriptive statistics of masseter variables in different growth pattern groups

Parameter	Horizontal growth pattern				Neutral growth pattern				Vertical growth pattern				p
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	
Volume (cm^3)	15.4	35.5	25.0	6.16	11.2	32.1	22.1	5.46	13.8	28.4	19.5	4.58	0.006
CSA (mm^2)	379.1	650.9	518.2	78.0	293.9	673.2	470.2	104.74	327.9	601.8	428.7	77.61	0.008

Table 4. Descriptive statistics of medial pterygoid variables in different growth pattern groups

Parameter	Horizontal growth pattern				Neutral growth pattern				Vertical growth pattern				p
	Min	Max	mean	SD	Min	Max	mean	SD	Min	Max	mean	SD	
Volume (cm^3)	7.8	21.8	11.3	3.5	5.2	21.9	10.1	3.04	6.0	22.3	10.3	4.7	NS
CSA (mm^2)	188.6	409.1	308.2	67.1	160.8	413.9	290.4	59.7	129.1	431.0	281.5	81.0	NS

Table 5. Descriptive statistics of mandibular variables (mm) in different growth pattern groups

Parameter	Horizontal growth pattern				Neutral growth pattern				Vertical growth pattern			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Inter-Co distance med	71,9	91,4	81,5	5,1	71,7	122,4	82,5	8,54	71,3	94	83,1	5,93
Inter-Co distance lat	107.2	133.3	118.9	7.69	86	132	114.8	8.26	103.3	124.3	116	6.6
Inter-Ang distance	80.8	112.5	96.5	9.24	79.1	110	96.2	8.44	78.3	106.8	96.7	6.94
Md overall length	104.5	139.1	117.8	11.5	104	136.4	119.2	8.9	91.5	143.5	119.4	12.4
Height of Md ramus	52.7	74.9	62.1	6.4	46.7	75.7	60.9	6.1	41.7	95.7	59.5	10.2
Length of Md corpus	67.1	92.3	79.1	7.6	63.5	91.2	78.6	6.2	61.1	95.2	76.3	8.2

Co – condylar; Md – mandibular; Ang – angular; med – medial; lat – lateral.

Of the seven variables included in regression analysis (volume and CSA of masseter, volume and CSA of medial pterygoid, mandibular overall length, height of mandibular ramus and length of mandibular corpus) in the final model, only four variables were significantly associated with MP-SN and explained 37% of the variance (masseter volume (p=0.017), mandibular overall length (p<0.001), height of mandibular ramus (p=0.003) and length of mandibular corpus (p<0.001)).

DISCUSSION

To our knowledge, this is the first attempt to acquire and merge data from MRI and CBCT in this field of research. In most of the previous studies in which mandibular muscles have been investigated using MRI or US, the method of choice for the craniofacial skeletal structures have been conventional lateral cephalometry in contrast to this study, in which the measurements were performed on both sides of the mandible.

In correspondence with data of literature, specific radiological methods like MRI (11-13, 20, 26, 27) and CBCT (29, 31) for the craniofacial area evaluation were selected and used with the aim of providing higher accuracy of soft and hard tissue investigation and analysis.

All study samples

The observed significant inter-muscular and inter-parameter correlation relates to the cooperative and coordinating actions of the masseter and medial pterygoid elevator muscles. These results are in agreement with some previous studies (10-12, 21, 22) and contrasts with some as well (23).

The mean values of volume and CSAs for the masseter in this study were 21.9 cm^3 and 4.7 cm^2 in comparison with the mean values of previous studies that assessed muscle parameters in adults with the closest values of 4.8 cm^2 for the CSA (12), 21.2 cm^3 and 5.0 cm^2 (22). Other studies showed higher mean values of 22.9 cm^3 and 4.83 cm^2 (11), 29.2 cm^3 and 5.5 cm^2 (20), 30.4 cm^3 and 6.9 cm^2 (21), respectively. The mean values of the medial pterygoid muscle in this study for the volume and CSA were 10.5 cm^3 and 2.9 cm^2 in comparison with previous studies, with the closest values of 10.4 cm^2, 3.0 cm^2 (20) and 3.3 cm^2 for the CSA (12), 10.4 cm^3 and 3.2 cm^2 (11), 9.3 cm^3 and 3.4 cm^2 (22). The direct comparison should be assessed with caution, and the factors of dentofacial deformity, ethnicity, sex, age and methodology should not be ignored.

Comparison of the study groups

Significantly larger masseter parameters and a tendency of medial pterygoid to be larger in the

Table 6. Correlations between muscular and mandibular skeletal parameters in the neutral growth pattern group

	Md ramus height	Md corpus length	Md overall length	Inter-angular distance	Intercondylar medial distance	Intercondylar lateral distance
Volume of masseter	0.6**	0.5**	0.5**	0.3	-0.08	0.18
Masseter CSA	0.4*	0.45**	0.3*	0.2	0.06	0.05
Volume of MPM	0.4**	0.4**	0.4**	0.08	-0.0	0.16
MPM CSA	0.1	0.17	0.02	-0.03	-0.01	-0.2

Md – mandibular; CSA – cross-sectional area; MPM – medial pterygoid muscle. * – P=0.05; ** – P=0.01.

Table 7. Correlations between muscular and mandibular skeletal parameters in the horizontal growth pattern group

	Md ramus height	Md corpus length	Md overall length	Inter-angular distance	Intercondylar medial distance	Intercondylar lateral distance
Volume of masseter	0.4	0.3	0.4	0.3*	0.68**	0.74**
Masseter CSA	0.3	0.3	0.3	0.4	0.3	0.4
Volume of MPM	0.2	0.4	0.4	-0.0	0.4	0.3
MPM CSA	0.2	0.2	0.3	0.1	0.3	0.3

Md – mandibular; CSA – cross-sectional area; MPM – medial pterygoid muscle. * – P=0.05; ** – P=0.01.

Table 8. Correlations between muscular and mandibular skeletal parameters in the vertical growth pattern group

	Md ramus height	Md corpus length	Md overall length	Inter-angular distance	Intercondylar medial distance	Intercondylar lateral distance
Volume of masseter	0.1	0.33*	0.3	0.3	0.3	0.47*
Masseter CSA	-0.1	0.22	0.1	0.07	0.25	0.23
Volume of MPM	0.3*	0.3*	0.5*	-0.1	-0.6	0.13
MPM CSA	-0.01	0.18	0.05	0.12	0.2	0.04

Md – mandibular; CSA – cross-sectional area; MPM – medial pterygoid muscle. * – P=0.05; ** – P=0.01.

horizontal growth pattern groups in comparison with the vertical growth pattern groups were observed. This finding is in agreement with previous data (8-12). The observed differences in size (volume and CSA) of the largest elevator muscles among the vertical and horizontal groups point to different mechanical loading patterns of different growth pattern mandibles (12).

At the same time, we observed a statistically significant negative correlation between MP-SN (the criteria for the vertical craniofacial dimension) and most of the muscular variables in the overall sample. This tendency indicates that the steeper the mandibular plane or higher divergency of the facial morphology is, the smaller, thinner or weaker will be the masseter and medial pterygoid. This finding is in agreement with various reports (9-12).

Interaction between parameters of muscles and mandible

To identify form and function relationships in individuals with different vertical craniofacial growth patterns, a profound analysis was performed separately in the neutral, horizontal and vertical growth pattern groups. Correlations between masticatory muscles and mandibular parameters were inconsistent among the study groups. This correlation pattern can be explained only by different modes of biomechanical action of the elevator muscles in different growth pattern groups.

In general, higher and more significant correlations between the investigated muscles and mandibular structures were observed in the neutral growth pattern group. The masseter, in particular, exerted stronger and more frequent correlations with the skeletal structures of the mandible in all study groups (30).

The volume parameter showed stronger associations than CSA, which is in line with the results obtained by another researcher, who showed that muscle volume is better related to vertical craniofacial dimension than CSA (11).

The values of the transversal dimension (intercondylar and inter-angular measurements) of the mandible significantly correlated with masseter volume only in individuals with a horizontal growth pattern. Considering the significant observations of strong musculature in the horizontal growth pattern group in comparison with the other groups, we consider that strong masticatory muscles are associated with the transversal dimension of the mandible and thus with the craniofacial morphology. This fact is supported by other researchers, who suggested that individuals with strong mandibular muscles have a tendency towards wider craniofacial morphology (10, 23, 24).

According to Kiliaridis' opinion (25) and Frost's theory (2), masticatory muscles can influence craniofacial growth in humans, provided that the force they apply to the bone is above a certain threshold. The strength of a muscle must reach a certain force level in order to exert influence on the bone and observe definite consequences. Thus, individuals with strong masticatory muscles are more homogenous (normo- or hypodivergent) than individuals with weak muscles who show great variability with respect to the vertical craniofacial dimension, and this feature can be attributed to the results of the current study.

CONCLUSIONS

The anatomical morphology (volume and CSA) of the masseter and medial pterygoid demonstrates variability and differences among individuals with different vertical facial morphology. Individuals with underlying horizontal growth pattern demonstrate significantly larger parameters of volume and CSA of the masseter in contrast to individuals with underlying vertical growth patterns. The masseter seems to be more sensitive to the variation in craniofacial growth patterns than the medial pterygoid muscle. Volume as the biomechanical characteristic seems to be a more significant parameter for the craniofacial area than CSA.

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