RĪGAS STRADIŅA UNIVERSITĀTE

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MORPHOLOGY OF THE MASTICATORY MUSCLES AND THE MANDIBLE IN A 3D IMAGE OF PATIENTS WITH DENTOFACIAL DEFORMITIES

Summary of the Doctoral Thesis
for obtaining the degree of a Doctor of Medicine

Speciality – Orthodontics

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The study was carried out at The Department of Orthodontics and the Department of Radiology of the Institute of Stomatology of Rīga Stradiņš University and the Department of Radiology of Riga East University Hospital.

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Doctoral Thesis is available in the RSU library of and at RSU webpage: www.rsu.lv.

Secretary of the Promotional Council:

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THE ABBREVIATIONS USED

2D	two-dimensional
3D	three-dimensional
ALFH	anterior lower facial height
ANB	the anteroposterior relationship between the mandible and the maxilla
ANOVA	*Analysis of variance* (Dispersion analysis)
ATFH	anterior total facial height
CBCT	cone beam computed tomography
cm^2	square centimetre
cm^3	cubic centimetre
CSA	cross-sectional area
CSA	cross-sectional area
CT	computed tomography
FH-MP	Frankfurt horizontal-mandibular plane angle
MAS	*musculus masseter*
Max	maximum value
Mean	mean value
Min	minimum value
mm	millimetre
MM	maxillary-mandibular plane angle
MPM	*musculus pterygoideus medialis*
MP-SN	mandibular plane-cranial base angle
MRI	magnetic resonance imaging
MSCT	multi-slice computed tomography
N	number of patients
p	statistical confidence level
r	*Pearson* correlation coefficient
SD	variable standard deviation
SNA	angle representing the anteroposterior position of the maxilla relative to the cranial base
SNB	angle representing the anteroposterior position of the mandible relative to the cranial base
US	ultrasonography

1. INTRODUCTION

The quality of life of individuals with dentofacial deformities is lower than the quality of life of individuals without these types of pathologies (Lee et al., 2007), and therefore the analysis and research of various aspects in this field of science are topical and important.

The importance of the masticatory muscles in the speciality of orthodontics is related to several aspects: aetiology of dentofacial deformities, the course of the treatment process, the selection of orthodontic appliances, and the long-term stability of the treatment results (Hunt et al., 2006). Successful muscle adaptation that includes the reorganization and regeneration of the muscle fibres is fundamentally important for ensuring that the process and results of orthodontic-orthopaedic, myofunctional and orthognathic treatment is successful in various cases of dentofacial deformation. In the maxillofacial area, the masticatory muscles take part in the creation of the biomechanical environment, and this, according to Moss' function matrix theory and the classic Wolff's law of bone formation, may influence the skeletal components, their growth and development, as well as the final anatomical morphological manifestation in the dentofacial structures. The aforementioned mechanisms are directly attributable to the mandible that belongs to the load-bearing bones of a human body, and is an important dentofacial deformity component in the sagittal and in the vertical plane.

Currently, when initiating orthodontic treatment, a specialist carries out a primary clinical investigation by assessing intraoral and extraoral indications in all planes, with subsequent radiological in-depth examination, the necessity of which is based on the severity of the clinical findings, the planning and overall necessity of further treatment. These days, image diagnostic methods provide possibilities to examine patients by using three-dimensional imaging and by applying specific radiological investigation methods to each tissue group. In this research, the magnetic resonance imaging was used for the examination of soft tissues i.e., muscles, but the cone beam computed tomography was used for full examination, evaluation and further analysis of hard tissues, i.e. the mandible.

The novelty of this research is linked to and is based on literature data showing that until now the research in this direction of science has mainly been targeted towards the relation and influence of the masticatory muscles to the vertical and transversal dimension of the craniofacial structures in general, but there are no researches that include simultaneous studies and comparison of the morphological characteristics of the masticatory muscles and the mandible (as a craniofacial structure) in relation to the vertical and the sagittal plane in individuals with dentofacial deformities. Also, no researches have been found combining separately obtained magnetic resonance imaging data and cone beam computed tomography data into a 3D picture.

1.1. Objective of the thesis

To study the spatial parameters of the masticatory muscles in an MRI image, the structural characteristics of the mandible – in a CBCT image, and their mutual relation in the sagittal and the vertical plane in patients with dentofacial deformities.

1.2. Tasks of the thesis

1. To develop an MRI and CBCT examination protocol for the spatial parameters of the masticatory muscles and the parameters of the mandibular skeletal structures for this study.

2. To measure and to analyse *musculus masseter*, *musculus pterygoideus medialis* and the mandibular skeletal structures in individuals with dentofacial deformities in the sagittal and in the vertical plane.
3. To compare the spatial parameters of *musculus masseter*, *musculus pterygoideus medialis* and the parameters of the mandibular skeletal structures among Skeletal Class I, II, III, and among the horizontal, neutral and vertical craniofacial growth type groups.
4. To evaluate the connection between *musculus masseter*, *musculus pterygoideus medialis* and the mandibular skeletal structures separately within Skeletal Class I, II, III, and horizontal, neutral and vertical craniofacial growth type groups.
5. To establish the significance and influence of *musculus masseter, musculus pterygoideus medialis with dentofacial dialis* and the mandibular skeletal structures on the skeletal class in the sagittal plane and on the craniofacial growth type in the vertical plane.
6. To establish which of the parameters of the researched muscles – the volume or the cross-sectional area – is a more meaningful parameter in the craniofacial area.

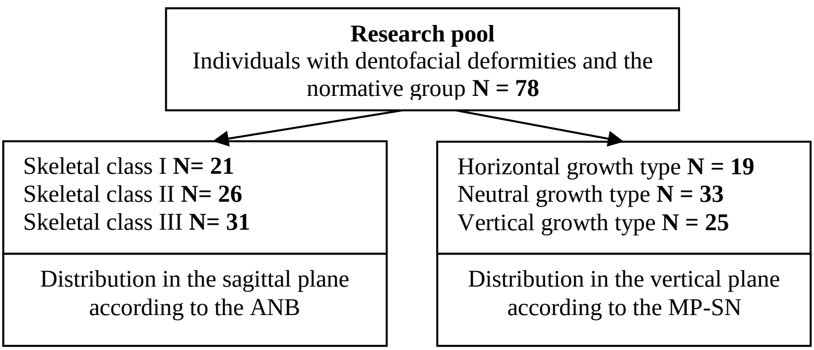
1.3. Hypothesis of the thesis

1. In individuals with dentofacial deformities there is mutual correlation between the spatial parameters of the masticatory muscles and the anatomical structural peculiarities of the mandible.
2. The dentofacial deformities in the sagittal and vertical planes are characterized by different spatial parameters of the masticatory muscles and radiological parameters of the mandible.

2. MATERIAL AND METHODS

2.1. Material

The research included 78 patients with Class II and III dentofacial deformities before the planned combined orthodontic and orthognathic surgery treatment from the year 2005 to 2012, and individuals of the skeletal Class I as the normative group. The researchable groups were formed on the basis of clinical and radiological diagnostic CBCT examinations performed in the lateral cephalometric images. This approach facilitated the distribution of the involved patients into two research directions according to specific criteria in the sagittal plane (according to the ANB angle, that reflects the mutual skeletal relations of maxilla and mandible in the sagittal plane with a mean value of $2^\circ \pm 2$ (Jacobson, 1995). *Wits* analysis indicates the distance between two perpendiculars drawn against the occlusal plane from point A (the parameter of the maxilla) and point B (the parameter of the mandible), and in the vertical plane (according to MP-SN angle measured between the *mandibular* plane MP (*gonion – gnathion*) (Jakobson, 1995) and the anterior cranial base SN (*sella – nasion*) with a mean value of $32^\circ \pm 5$ (Bell et al., 1980; Profitt et al., 2007). The distribution of the individuals according to the criteria is illustrated in Picture 2.1.



Picture 2.1. **Research groups**

The mean age of the patients in skeletal class I, II, and III were 24.1 years, 18.9 years and 20.4 years, respectively; and in horizontal, neutral and vertical growth type groups – 20.6 years, 21.7 years, and 20.1 years. The distribution of the patients according to their gender into classes and growth type groups is shown in tables 2.1. and 2.2.

Table 2.1.

Distribution of the patients into classes according to their gender

Class	Gender				Total	
	Men		Women		n	%
	n	%	n	%		
Skeletal Class I	8	38.1	13	61.9	21	100
Skeletal Class II	12	46.2	14	53.8	26	100
Skeletal Class III	17	54.8	14	45.2	31	100
Total	37	47.4	41	52.6	78	100

Table 2.2.

Distribution of the patients into growth types in relation to their gender

Growth type	Gender				Total	
	Men		Women		n	%
	n	%	n	%		
Horizontal	10	52.6	9	47.4	19	100
Neutral	16	48.5	17	51.5	33	100
Vertical	11	44.0	14	56.0	25	100
Total	37	48.1	40	51.9	77	100

2.2. Methods

2.2.1. Magnetic resonance imaging (MRI) examination of masticatory muscles

Examination protocol

The examination was performed using a 1,5T *GE MEDICAL SYSTEMS Signa HDx* magnetic resonance imaging unit.

The positioning of the patient during the examination was standardised: in supine position, awake, shallow and calm breathing during the examination, swallowing saliva before scanning and not swallowing saliva during the scanning, with the mouth closed. The patient's head was positioned in the axial medium orbitomeatal plane, parallel to the cranial base.

The following MRI examination series were carried out: T1SE sagittal, FSE T2 axial, STIR T2 coronal, 3D SPGR T1, as well as the post-processing of the date: the reconstruction of the obtained 2D and 3D images. Slice thickness: 2 mm; inter-slice gap: 2 mm; FOV 24 x 18.

For the volumetric and cross-sectional area measurements, the automatic 3D volumetric and 2D morphometric applications available in the MRI workstation were used.

To obtain the values of the 3D volume and the 2D area values, the radiologist manually marked the boundaries of the examined anatomic structure (i.e. the examined muscle) in the 3D SPGR T1 images, and after that applied the relevant processing applications. To obtain the volumetric data the cross-sectional contours of a muscle, depending on its segment, were marked every 2 to 6 mm along the whole length of the muscle. In the automated 3D volumetric application the volume was calculated by multiplying the successive cross-sectional areas with the slice thickness and the sum of the inter-slice gap ($cm^3 = A_1 + A_2 + A_3 \ldots + A_n) \times$ (slice thickness + inter-slice gap).

In the automated 2D morphometric software the cross-sectional area of a muscle was calculated from the middle part – the largest cross-sectional slice.

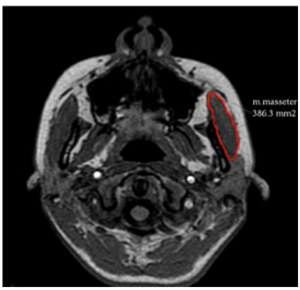
Processing of the obtained data, analysis and spatial measurements of the masticatory muscles

Two masticatory muscles were measured and analysed:

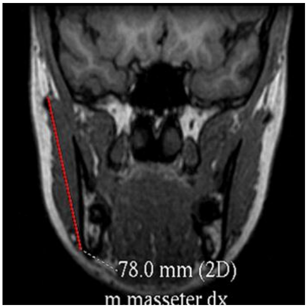
1. *Musculus masseter*: (a) the maximum cross-sectional area (cm^2) in the middle point of the ramus of the mandible (Picture 2.2.), (b) the length i.e., the craniocaudal dimension measurement (mm) (Picture 2.3.) and (c) volume (cm^3).
2. *Musculus pterygoideus medialis*: (a) the cross-sectional area (cm^2) (Picture 2.4.), (b) the length i.e., craniocaudal dimension measurement (mm) and (c) volume (cm^3).

The cross-sectional area was measured perpendicularly to the longitudinal axis of the muscle, according to *Goto* et al. (2002), in the middle of the muscle, but the maximum cross-sectional area was determined as the largest mean measure in the adjacent slices (*Boom* et. al, 2008; *Van Sronsen*., 2010).

All measurements were performed mutually and by one radiologist; the measurements were done twice with a two-week interval.



Picture 2.2. **MRI axial 3D SPGR T1 image, chosen at the level of the largest cross-section of the muscle**



Picture 2.3. **The length of *musculus masseter* in the coronal plane**

Picture 2.4. **The cross-sectional area of *musculus pterygoideus medialis* in the axial plane**

2.2.2. Cone beam computed tomography examination of the maxillofacial area – the cephalometric and mandibular linear parameters

Examination protocol

The examination was carried out by using cone beam computed tomography (CBCT) equipment iCAT (*iCAT Next Generation*, *Imaging Sciences International*, *Inc. Hatfield*, *PA*, USA). The standardized equipment operation protocol: voltage – 120 kV, electric current – 5 mA. The selected field of view (FOV) was 17 cm, resolution – 0.4 vox volumetric units, with total exposure time of 7 seconds.

The positioning of the patient during the examination was standardised: in sitting position, the head held in motionless position, the eye–gaze directed straight ahead, the mouth closed, the teeth lightly squeezed in the central position.

Processing of the obtained data, analysis and mandibular measurements

The images were processed, reconstructed and analysed by using *examVision* software *(Imaging Sciences International, Inc. Hatfield, PA, USA*). The picture was reconstructed in the sagittal, coronal and axial planes for finding an optimal section (Picture 2.5.).

The standard lateral cephalometric analysis in CBCT images was carried out in the application *Dolphin*, version 11.0 (*Dolphin Imaging*, *CA*, USA). During the analysis of the images the following standard measurements were performed: angles SNA, SNB, ANB, MM, Go, MP-SN, Wits analysis, the calculation of the face height proportion ALFH: ATFH.

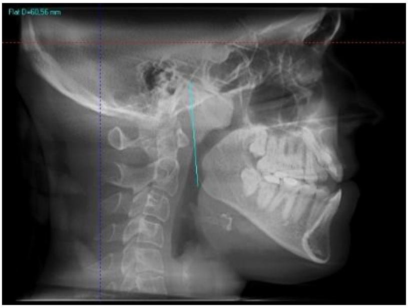
A B

C

Picture 2.5. **Axial (A), sagittal (B) and coronal (C) planes in a CBCT image**

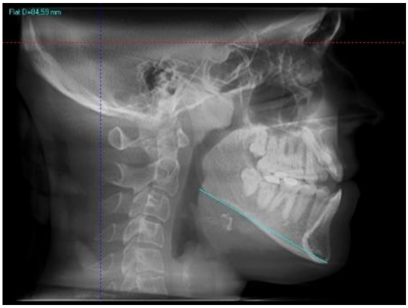
For the evaluation of the mandibular spatial parameters the following linear measurements were carried out in the axial, sagittal, coronal planes:

1. The length of the ramus of the mandible - the linear distance between the cephalometric points *Condylus – Gonion* (*Condylus* - the highest and the most posterior point of the head of the mandible; *Gonion* – a constructed point of intersection between the tangent of the lower edge of the mandible and the posterior tangent of the ramus of the mandible) was measured in the sagittal plane, separately in the right and the left sides (Picture 2.6.).



Picture 2.6. **The measurement – the length of the ramus of the mandible in the CBCT image**

2. The length of the body of the mandible – a linear distance between the cephalometric points *Gonion – Gnathion* (*Gonion* – a constructed point of intersection between the tangent of the lower edge of the mandible and the posterior tangent of the ramus of the mandible; *Gnathion* – the lowest anterior point of the mandible) was measured separately in the sagittal plane, on the right and left sides (Picture 2.7.).

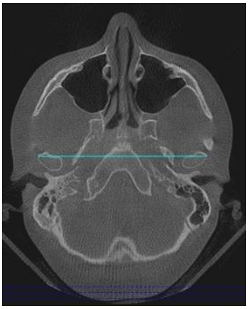


Picture 2.7. **The measurement – the length of the body of the mandible in the CBCT image**

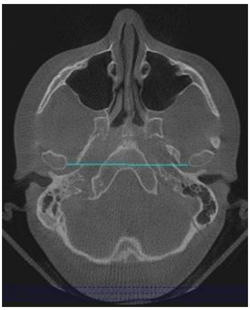
3. The total length of the mandible – a linear distance between the cephalometric points *Condylus* – *Gnathion* (*Condylus* – the highest distal point of the head of the mandible; *Gnathion* – the lowest anterior point of the mandible) was measured separately in the sagittal plane, on the right and left sides (Picture 2.8.).

Picture 2.8. **The measurement – the total length of the mandible in the CBCT image**

4. The *intercondylar* measurements: the *intercondylar* distance between the medial poles of *Condylus* and the *intercondylar* distance between the lateral poles of *Condylus*, were measured in the axial plane (Picture 2.9. and 2.10.).



Picture 2.9. **The measurement – the lateral *intercondylar* distance in the CBCT image**



Picture 2.10. **The measurement – the medial *intercondylar* distance in the CBCT image**

5. *Interangular* measurement – the linear distance between the lowest posterior points of the *angulus* of the mandible was measured in the coronal plane (Picture 2.11.).

Picture 2.11. **The measurement – the *interangular* distance in the CBCT image**

The muscle measurements and the mandibular measurements were carried out by one specialist. The measurements were carried out bilaterally – on the right and the left sides, twice with a two week interval between the measurements. To determine the measurement error for all measurements the measurement error was calculated according to Dahlberg's method (Dahlberg, 1940). $Se = \surd (D2/N)$. The measurement error of any measurement did not exceed the determined threshold value of 1.0.

The statistical processing of the data involved the use of descriptive and analytical statistical methods: descriptive statistics, *one – way ANOVA* analysis with Bonferoni correction, Pearson correlation coefficients, and multifactorial regression analysis.

3. RESULTS

3.1. General characteristics of the study group

Table 3.1.

The descriptive statistics of cephalometric, muscle and mandibular measurements

Indicator	Min	Max	Mean	SD
SNA (°)	73.6	89.8	81.4	3.76
SNB (°)	67.6	98.5	80.8	6.8
ANB (°)	−13.5	13.7	0.52	6.1
Wits (mm)	− 34	26	−3.4	12.1
MP-SN (°)	8.6	53.6	32.6	8.65
MM (°)	8.5	48.6	27.5	8.92
ALFH : ATFH (%)	48.8	63.2	56.7	3.07
Volume of *musculus masseter* (cm^3)				
Right side	11.2	35.0	21.83	5.71
Left side	11.1	35.87	22.11	5.82
Musculus masseter CSA (cm^2)				
Right side	2.88	6.71	4.61	0.94
Left side	2.92	7.22	4.73	1.00
Volume of *musculus pterygoideus medialis* (cm^3)				
Right side	4.88	23.69	10.28	3.78
Left side	5.23	22.88	10.66	3.84
Musculus pterygoideus medialis ŠGL (cm^2)				
Right side	1.17	4.26	2.86	0.67
Left side	1.33	4.79	2.97	0.73
Intercondylar distance between the medial poles (mm)	71.3	122.4	82.36	6.98
Intercondylar distance between the lateral poles (mm)	86	133.3	116.09	7.69
Interangular distance (mm)	78.3	112.5	96.32	8.16
Total length of the mandible (mm)				
Right side	92.4	144.7	119.43	10.9
Left side	90.6	142.4	118.47	11.09

Continuation of Table

Indicator	Min	Max	Mean	SD
Height of the ramus of the mandible (mm)				
Right side	44	99.2	60.97	7.96
Left side	39.5	99.1	60.67	8.03
Total length of the body of the mandible (mm)				
Right side	61.8	96.6	78.24	7.49
Left side	60.5	93.8	77.69	7.23

Although the muscle and mandibular measurements on the right and the left side differed, this difference was statistically reliable in few measurements only, and well pronounced superiority of one or another side was not observed. Furthermore, the correlation coefficients between the right side and the left side measurements in all cases were high ($r = 0.95–0.97$, $p < 0.001$). For this reason, in further analysis the right side and left side mean parameters were used for both muscle and bone measurements.

3.2. Cephalometric parameters

<u>Skeletal Class I, II and III</u>

The cephalometric indicators are related to and characterise the mutual anatomical relationship of the maxilla, the mandible, and the cranial base in the sagittal plane are separately gathered in each of the classes, see Table 3.2.

Table 3.2.

Cephalometric parameters in skeletal class I, II and III

Indicator	Class I				Class II				Class III				p value
	Min	Max	**Mean**	SD	Min	Max	**Mean**	SD	Min	Max	**Mean**	SD	
SNA	75	85.9	**81.0**	3.08	75.7	89.8	**82.0**	3.73	73.6	89.6	**81.1**	4.23	NS
SNB	70.9	85.2	**78.8**	3.33	67.6	81.3	**74.9**	4.01	76.3	98.5	**86.9**	5.36	<0,0001
ANB	1.7	4	**1.9**	1.85	4	13.7	**7.2**	2.06	−13.5	−1.3	**−5.9**	2.9	<0,0001

<u>Horizontal, neutral and vertical growth type groups</u>

Cephalometric parameters, which are related to and characterise the changes of skeletal structures in the vertical plane and also determine the craniofacial growth type, are separately summarised into each of the growth type groups, see Table 3.3.

Table 3.3.

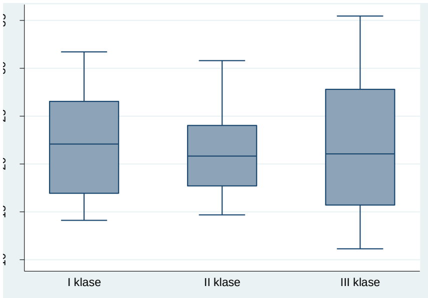
Cephalometric parameters in the neutral, horizontal and vertical growth type groups of patients

Indicator	Neutral growth type				Horizontal growth type				Vertical growth type			
	Min	Max	**Mean**	SD	Min	Max	**Mean**	SD	Min	Max	**Mean**	SD
MP-SN (°)	27	37	**31.5**	3.18	8.6	26.9	**21.9**	5.06	37.5	53.6	**42**	4.50
MM (°)	19.4	48.4	**26.9**	5.83	8.5	24.5	**17.4**	4.46	25.7	48.6	**35.9**	6.09
ALFH: ATFH (%)	53.1	61.5	**56.9**	2.38	48.8	60.9	**54.5**	3.63	52.7	63.2	**58**	2.52

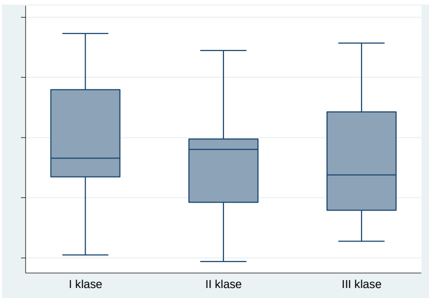
3.3. Comparison of muscular and mandibular parameters among the research groups

The comparison of the research groups was performed separately among Skeletal Class I, II, III, and among the horizontal, neutral and vertical craniofacial growth type groups.

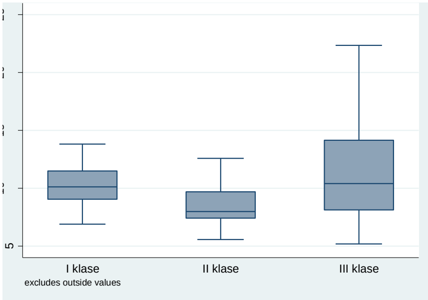
3.3.1. Comparison among Skeletal Class I, II and III



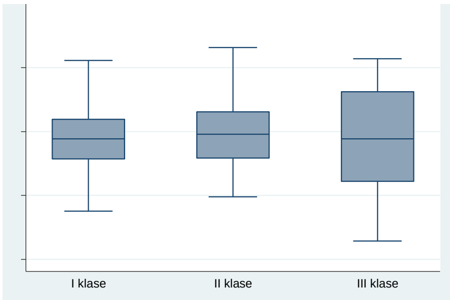
Picture 3.1. **The comparison of the volume of *musculus masseter* among Skeletal Class I, II and III**



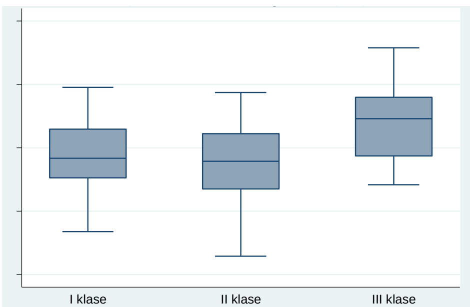
Picture 3.2. **The comparison of the cross-sectional area of *musculus masseter* among Skeletal Class I, II and III**



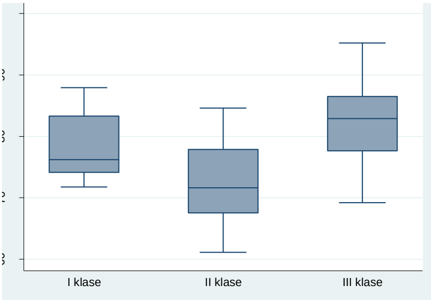
Picture 3.3. **The comparison of the volume of *musculus pterygoideus medialis* among Skeletal Class I, II and III**



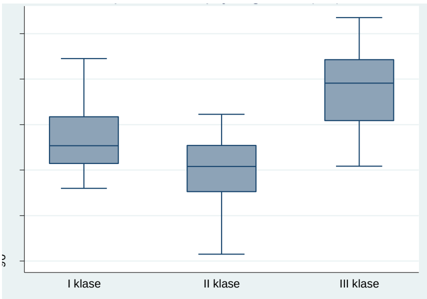
Picture 3.4. **The comparison of the cross-sectional area of *musculus pterygoideus medialis* among Skeletal Class I, II and III**



Picture 3.5. **The comparison of the height of the ramus of the mandible among Skeletal Class I, II and III**



Picture 3.6. **The comparison of the length of the body of the ramus of the mandible among Skeletal Class I, II and III**

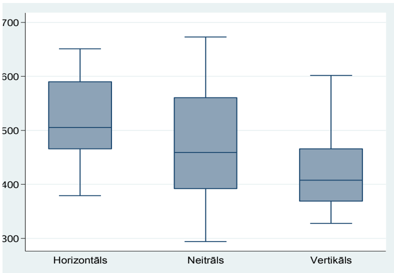


Picture 3.7. **The comparison of the total length of the mandible among Skeletal Class I, II and III**

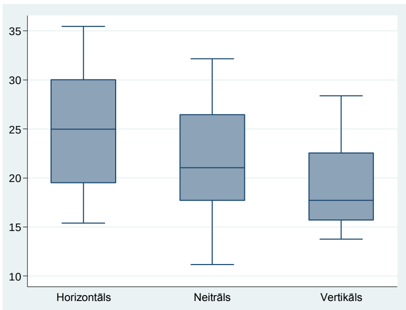
The comparison of the spatial parameters of muscles among Class I, II and III revealed that the lowest muscle volume parameters are in the Class II group.

The differences of the volume parameters of *musculus pterygoideus medialis* among the skeletal classes were statistically reliable (p = 0.038). This difference was ensured by the parameters of Class II and III. Statistically reliable differences in the cross-sectional area parameters of *musculus pterygoideus* among the groups were not observed. The volumetric parameters and the cross-sectional parameters of *musculus masseter* among the groups did not reliably differ statistically.

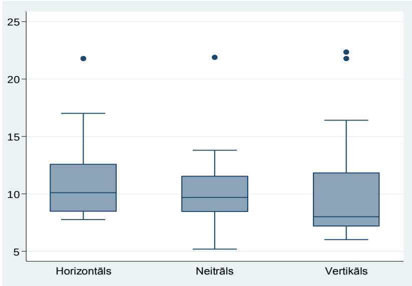
3.3.2. Comparison among the horizontal, neutral and vertical growth type group



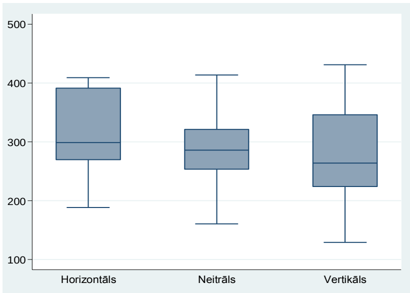
Picture 3.8. **Comparison of the cross-sectional area of *musculus masseter* among the horizontal, the neutral and the vertical growth type**



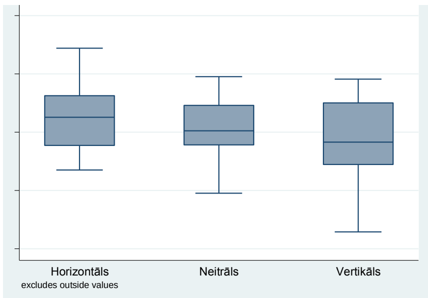
Picture 3.9. **Comparison of the volume of *musculus masseter* among the horizontal, the neutral and the vertical growth type**



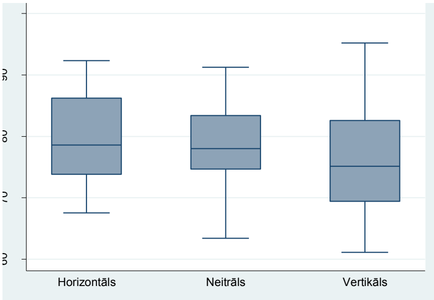
Picture 3.10. **Comparison of the volume of *musculus pterygoideus medialis* among the horizontal, the neutral and the vertical growth type**



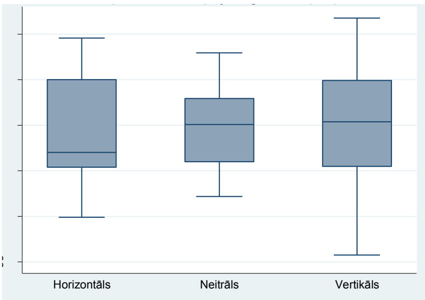
Picture 3.11. **Comparison of the cross-sectional area of *musculus pterygoideus medialis* among the horizontal, the neutral and the vertical growth type**



Picture 3.12. **Comparison of the height of the ramus of the mandible among the horizontal, the neutral and the vertical growth type**



Picture 3.13. **Comparison of the height of the body of the mandible among the horizontal, the neutral and the vertical growth type**



Picture 3.14. **Comparison of the total length of the mandible among the horizontal, the neutral and the vertical growth type**

The largest volume measurement of *musculus masseter* was found in the horizontal growth type group, and the smallest in the vertical growth type group (with high statistical reliability ($p < 0.006$)), but according to Bonferoni correction the statistical reliability remains only when comparing the volume of *musculus masster* between the horizontal growth type group and the vertical growth type group ($p < 0.004$).

The largest cross-sectional area measurement of *musculus masseter* was found in the horizontal growth type group, and the smallest in the vertical growth type group (with high statistical reliability ($p < 0.008$)), but according to Bonferoni correction the statistical reliability remains only when comparing the volume of *musculus masster* between the horizontal growth type group and the vertical growth type group (p < 0.006).

The volume measurements and the cross-sectional area measurements of *musculus pterygoideus medialis* across all the groups were approximately equivalent and did not reliably differ statistically.

3.4. Correlations between musculus masseter and musculus pterygoideus medialis, and the linear parameters of the mandible

In all the study group there was a strong correlation between the volume measurements and the cross-sectional area measurements of *musculus masseter* ($r = 0.8$, $p < 0.000$), and also medium strong correlation between the volume measurements and the cross-sectional area measurements of *musculus pterygoideus medialis* ($r = 0.5$, $p < 0.005$). Between the parameters of both muscles there were medium strong positive correlations: between the volume measurements of *musculus masseter* and *musculus pterygoideus medialis* ($r = 0.6$, $p < 0{,}000$), and correspondingly between the cross-sectional area measurements of these muscles ($r = 0.6$, $p < 0{,}001$).

The correlations between the ANB angle and the parameters of the volume and the cross-sectional area of *musculus masseter*, *musculus pterygoideus medialis* were calculated by analysing the research pool. A statistically significant and strong negative correlation was observed only between the volume of *musculus pterygoideus medialis* and the ANB angle ($r = -0.6$, $p = 0.002$).

Also the correlations between the MP-SN angle and the parameters of the volume and the cross-sectional area of *musculus masseter*, *musculus pterygoideus medialis* were calculated by analysing all the study group. Statistically significant negative correlations were observed between the ANB angle and the volume ($r = -0.5$, $p = 0.0003$) and the cross-sectional area ($r = -0.4$, $p = 0.002$) of *musculus masseter*, as well as between the MP-SN angle and the volume of *musculus pterygoideus medialis* ($r = -0.3$, $p = 0.05$).

3.4.1. Skeletal Classes I, II and III

Table 3.4.

Correlations among the measurement parameters of the muscles and the mandible in patients with Skeletal Class I

	Height of the ramus of the mandible	Length of the body of the mandible	Total length of the mandible	Inter angular distance	Inter condylar distance between the medial poles	Inter condylar distance between the lateral poles
MPM volume	0.53**	0.59**	0.46**	0.33	−0.06	0.31
MAS CSA	0.47**	0.57**	0.39	0.33	0.04	0.09
MPM volume	0.77**	0.52**	0.74**	0.33	−0.02	0.2
MPM CSA	0.48**	0.22	0.44**	−0.04	0.01	0.2

* $p \leq 0.05$; ** $p \leq 0.01$

Table 3.5.

Correlations among the measurement parameters of the muscles and the mandible in patients with Skeletal Class II

	Height of the ramus of the mandible	Length of the body of the mandible	Total length of the mandible	Inter angular distance	Inter condylar distance between the medial poles	Inter condylar distance between the lateral poles
MPM volume	0.48**	0.5**	0.44**	0.19	−0.02	0.49
MAS CSA	0.23	0.21	0.0	0.07	−0.07	0.05
MPM volume	0.43**	0.59**	0.48**	−0.018	0.01	0.5
MPM CSA	−0.14	0.15	−0.07	0.17	−0.02	−0.12

* $p \leq 0.05$; ** $p \leq 0.01$

Table 3.6.

Correlations among the measurement parameters of the muscles and the mandible in patients with Skeletal Class III

	Height of the ramus of the mandible	Length of the body of the mandible	Total length of the mandible	Inter angular distance	Inter condylar distance between the medial poles	Inter condylar distance between the lateral poles
MPM volume	0.26	0.5**	0.49**	0.36**	0.41**	0.5**
MAS CSA	0.17	0.4**	0.51**	0.28	0.29	0.48**

Continuation of Table

	Height of the ramus of the mandible	Length of the body of the mandible	Total length of the mandi ble	Inter angular distance	Inter condylar distance between the medial poles	Inter condylar distance between the lateral poles
MPM volume	0.27	0.41**	0.39**	−0.2	0.12	0.0
MPM CSA	0.0	0.41**	0.21	0.0	0.18	0.26

* $p \leq 0.05$; ** $p \leq 0.01$

3.4.2. Horizontal, neutral and vertical growth types

Table 3.7.

Correlations among the measurement parameters of the muscles and the mandible in patients with neutral growth type

	Height of the ramus of the mandible	Length of the body of the mandible	Total length of the mandible	Inter angular distance	Intercon dylar distance between the medial poles	Inter condylar distance between the lateral poles
MPM volume	0.57**	0.5**	0.5**	0.3	−0.08	0.18
MAS CSA	0.4**	0.45**	0.3**	0.2	0.06	0.05
MPM volume	0.5**	0.5**	0.5**	0.08	–0.0	0.16
MPM CSA	0.1	0.17	0.02	−0.03	–0.01	−0.2

* $p \leq 0.05$; ** $p \leq 0.01$

Table 3.8.

Correlations among the measurement parameters of the muscles and the mandible in patients with vertical growth type

	Height of the ramus of the mandible	Length of the body of the mandible	Total length of the mandible	Inter angular distance	Inter condylar distance between the medial poles	Inter condylar distance between the lateral poles
MPM volume	0.1	0.43**	0.3	0.3	0.3	0.47**
MAS CSA	−0.1	0.22	0.1	0.07	0.25	0.23
MPM volume	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

* $p \leq 0.05$; ** $p \leq 0.01$

Table 3.9.

Correlations among the measurement parameters of the muscles and the mandible in patients with horizontal growth type

	Height of the ramus of the mandible	Length of the body of the mandible	Total length of the mandible	Inter angular distance	Inter condylar distance between the medial poles	Inter condylar distance between the lateral poles
MPM volume	0.4	0.3	0.4	0.3**	0.68**	0.74**
MAS CSA	0.3	0.3	0.3	0.4	0.3	0.4
MPM volume	0.2	0.4	0.4	−0.0	0.4	0.3

Continuation of Table

	Height of the ramus of the mandible	Length of the body of the mandible	Total length of the mandible	Inter angular distance	Inter condylar distance between the medial poles	Inter condylar distance between the lateral poles
MPM CSA	0.2	0.2	0.3	0.1	0.3	0.3

* p≤ 0.05; ** p≤0.01

For the evaluation of the skeletal structure of the mandible and the influence of *musculus masseter* and *musculus pterygoideus medialis* on the skeletal class in the sagittal plane, multifactorial regression analysis was carried out. From five variable values (the total length of the mandible, the height of the ramus of the mandible, the length of the body of the mandible, the volume and the cross-sectional area of *musculus pterygoideus medialis*) initially included into the model, only the total length of the mandible ($p < 0.001$) and the volume of *musculus pterygoideus medialis* ($p = 0.029$) were the variable values that statistically reliably forecasted the ANB parameter and explained its 58 % change.

For the evaluation of the skeletal structure of the mandible and the influence of *musculus masseter* and *musculus pterygoideus medialis* on the craniofacial growth type, multifactorial regression analysis was carried out. From seven variable values (the total length of the mandible, the height of the ramus of the mandible, the length of the body of the mandible, the volume and the cross-sectional area of *musculus masseter*, the volume and the cross-sectional area of *musculus pterygoideus medialis*) initially included into the model, only the volume measurement of *musculus masseter* ($p = 0.017$), the total length of the mandible ($p < 0.001$), the height of the ramus of the mandible ($p = 0.003$) and the length of the body of the mandible ($p < 0.001$ were the variable values that statistically reliably forecasted the MP-SN parameter and explained its 37 % change.

4. DISCUSSION

This doctoral thesis investigates the connection between the spatial parameters of the masticatory muscles and the mandibular skeletal structures in individuals with dentofacial deformities, on the basis of criteria in the sagittal and the vertical plane. The work included the study of the structures of the muscles and bones by applying a specific radiological method intended for each separate tissue group i.e., by using MRI for the examination of the soft tissues, and CBCT for the examination of the hard tissues, including the compilation, analysis and determination of the mutual relationship of the data.

4.1. Study group

The research pool of this doctoral thesis was set up to include both women and men to reflect a similar gender ratio, similarly to some authors (Xu et al., 1994; Benington et al., 1999; Kwon et al., 2007; Boom et al., 2008; Chan et al., 2008; Ariji et al., 2000; Lione et al., 2013) and contrary to other authors, who in their studies, dedicated to the research of masticatory muscles, have included only representatives of one gender (Van Spronsen, 2010; Kitai et al., 2002; Gionhaku and Lowe, 1989). All individuals included in this research were adults, whose craniofacial soft and hard tissue growth has theoretically ended (Bishara un Jakobsen, 1998), and who are approximately eighteen years old or slightly older (Enlow, 1990), and for whom orthognathic surgery can be planned. In literature it is also possible to find researches dedicated to the analysis of masticatory muscles that include only growing individuals (Lione et al., 2013; Chan et al. 2008), however, most of the data available in this direction of science cover the analysis of adults.

In total, this research enrolled and analysed 78 individuals with various dentofacial deformities; a relatively large number when compared to other researches of the same theme – the largest research group (Ariji et al., 2000) consisted of 160 individuals – but the smallest group (Benington et al., 1999) consisted of only 10 individuals.

The research enrolled individuals with dentofacial deformities in the sagittal plane (Skeletal Class I, II and III), vertical plane (horizontal, neutral and vertical growth type) and individuals without any dentofacial deformities, defined as the normative group (Skeletal Class I, natural growth type). In literature it is possible to find studies that are related to masticatory muscles and craniofacial morphology, and contain in-depth analysis of such groups as dentoalveolar Class I (Goto et al., 2002, Hsu et al., 2001, Ariji et al., 2000, Lione et al., 2014), skeletal Class III (Ariji et al., 2000, Kitai et al., 2002), mandibular retrognathia (Dicker et al., 2007), various dentofacial deformities in the vertical dimension (Van Spronsen et al.,1999;2010, Lione et al., 2013; Chan et al., 2008, Boom et al., 2008), but the other studies are dedicated to the analysis of the masticatory muscles in various non-specifically marked orthodontic or orthognatic individuals.

4.2. Measurements of *musculus masseter, musculus pterygoideus medialis* and the mandible, the precision of the measurements

Measurements of the volume and the cross-sectional area

The size of the skeletal muscles can be characterized by several parameters. The spatial parameters measured and analysed in this research were the volume and the cross-sectional area. In order to avoid expected high measurement error risk, with reference to Mitsiopoulus (1998), several measurement parameters, such as the thickness (measurement in the *anterior-posterior* direction) and width (measurement in the *medio-lateral* direction), were omitted. The reason for this is related to the fact that it is practically impossible to perform accurate measurements of one anatomic localization slice repeatedly for all patients; it is also related to possible irregularity in the external contour of the muscles. These latter factors are also relevant to the measurement of the cross-sectional area, unless the analysis is performed for the maximum measurement of the cross-sectional area, which is the mean largest measurement in the adjacent slices (Boom et al., 2008, Van Spronsen, 2010).

The volume characterizes the load produced by the muscle, but the cross-sectional area characterizes the maximum isometric force the muscle produces in only a few episodes over the whole day (Miyamoto et al., 1996). Both the volume and the cross-sectional area were included and analysed in this research, because each of them characterizes another biomechanical property, and hypothetically both of them can be significant and make their contribution for the development of the craniofacial biomechanical environment, thus influencing the skeletal anatomical morphology of the mandible.

The cross-sectional area can be measured in various anatomical locations in relation to the muscle or the adjacent skeletal anatomical structures. In this research, the cross-sectional area was measured perpendicularly to the longitudinal axis of the muscle, according to Goto et al. (2002), in the middle of the muscle, but the maximum cross-sectional area was measured as the largest mean measure in the adjacent slices (Boom et. al, 2008, Van Sronsen et al., 2010). When measuring parallel to anatomical planes, there is a possibility to overestimate the actual size of muscles, particularly this is related to *musculus pterygoideus medialis,* because this muscle in the medio-lateral direction occupies a spatially large area (Goto et al., 2005).

General comparison of the mean parameters of the volume (cm^3) and cross-sectional area (cm^2) of *musculus masseter* and *musculus pterygoideus* *medialis*, which in this research were obtained from the whole pool and other research groups, to the data available in literature, revealed that these data are both similar (Boom et al. 2008, Van Spronsen et al., 1991; Xu et al., 1994), and considerably different (Hsu et al., 2001; Goto et al., 2002). We assume that these differences may be related to the different research groups and their differences in relation to the average age, gender, race, ethnic group and craniofacial morphology. A similar effect is caused by the data acquisition process that is directly related to the examination method and the examination protocol.

In this research, out of four human masticatory muscles only two – *musculus masseter* and *musculus pterygoideus medialis* – were measured and analysed. Justification for such approach is related to two aspects. Firstly, the attachment places i.e., the anatomical location and the physiological function of *musculus masseter* and *musculus pterygoideus medialis* hypothetically are more tied and may influence the morphology of the mandible, particularly in the vertical plane (Hunt, 2006). Secondly, on the basis of the findings of Van Spronsen et al. (1989), the specific morphology, complex anatomic peculiarities, and the position (against the middle-sagittal plane) of other masticatory muscles (*musculus temporalis* and *musculus pterygoideus lateralis)*, can cause muscle measurement uncertainties with a high probability of measurement errors.

In this research, all the parameters of the muscles were measured in both sides, but similarly to Boom et al. (2008), Weijs and Hillen (1984), Dicker et al. (2012) and Bakke et al. (1991), in further analysis we used the mean values of the left and right side. Although the measured values of the volume and the cross-sectional area of the *musculus masseter* and *musculus pterygoideus medialis* and mandibular measurements in the right and in the left side differed, this difference was statistically reliable only in few measurements and pronounced superiority of one or another side was not observed.

Furthermore, the correlation coefficients between the right side and the left side measurements in all cases were high (r = 0.95–0.97, p < 0.001). Similar approaches can be found in literature where high correlation between the measurements of the cross-sectional area of the right and the left *musculus masseter* (Van Spronsen et al., 1991, 1992, Ariji et al., 2000, Chan et al., 2008) was proved. There are some authors who only analyse the measurements of one of the sides (Goto et al., 2002; 2005). Only Raadsheer et al., (1994) found well pronounced asymmetry between the measurements of the thickness of *musculus masseter* in both sides, and explained it with the lack of visualization and accuracy the ultrasonography has, as a method of radiology.

The data available in literature reveal that a cross-sectional area (as one of the parameters of the muscle size) very strongly and with high statistical reliability correlates with the volume parameter of the same muscle; this was discovered by Gionhaku and Lowe, (1989), Xu et al., (1994) when studying *musculus masseter* and *musculus pterygoideus medialis*. Other authors describe strong correlations between the measurements of the volume and the measurements of the cross-sectional area of *musculus masster* and *musculus pterygoideus medialis* (Gionhaku and Lowe, 1989, Hannam and Wood, 1989, Xu et al., 1994, Chan et al., 2008, Van Spronsen, 2010), or do not reveal any significant relationship (Van Spronsen et al., 1991). The results of our research are in line with the aforementioned data on correlations between the parameters of the muscles. The results suggest close co-action of both muscles and the possibility to calculate the volume of the muscle, knowing only the cross-sectional area, which can be used as a morphological indicator.

In publications of other research, the volume and the cross-sectional area of muscles is obtained by using magnetic resonance imaging, computed tomography, or ultrasonography. In this research, for the examination and measuring of muscles we choose magnetic resonance imaging, because this method of radiology originally was developed specifically for the examination of soft tissues. Magnetic resonance imaging allows measurements and reconstructions in all planes (multi-plane capacity), the use of this method does include the use of ionizing radiation, and does not cause any biologically cumulative consequences to patients (Brown, 2003), and this method, according to the date found in literature, has been widely used from 1989 until now.

It shall be noted that multi-slice computed tomography (MSTC) not only makes it possible to obtain high-quality measurements of *musculus masseter* and *musculus pterygoideus medialis* (Van Spronsen, 2010; Chan et al, 2008; Cavalcanti et al., 2004), but also provides an opportunity to make both bone and muscle measurements thus saving the patient time and financial resources. However, for practical, technical and biological reasons MSTC is not applicable for orthognathic patients (Farman et al., 2009), who undergo planned CBCT examinations before and after their orthognathic surgery, and this also applies to the model of this research.

Mandibular measurements

In this research the linear, trasversal linear measurements of the skeletal structures of the mandible, as well as the standard analysis of lateral cephalometry, including its angle measurements in the sagittal and the vertical plane we were interested in, were carried out and analysed using cone beam computed tomography radiology method that is based on and in line with several modern sources of literature (Katayama et al., 2014; Halicioglu et al., 2014; Salih et al., 2016, Farman et al., 2009; Hilgers et al., 2005; Lamichane et al., 2009, Maki et al., 2003).

4.3. Comparison of the study groups

Taking into account that in this doctoral thesis the dentofacial deformities were structured and the research groups were created according to criteria in the sagittal and the vertical plane, also the spatial parameters of the masticatory muscles and the parameters of the mandibular skeletal structures were compared separately between the Skeletal Classes I, II, III and between the craniofacial growth type groups.

Comparison among Skeletal Classes I, II and III

Our results of the study indicate that smaller parameters of *musculus pterygoideus medialis* and *musculus masseter* occur in the individuals that belong to Skeletal Class II.

Among Skeletal Classes I, II and III only the parameter of volume of *musculus pterygoideus mediali* differs with high statistical reliability: the largest muscles are observed in the Class III group, and the smallest in the Class II group, where the parameters correspondingly are 11.8 cm^3 and 9.2 cm^3, and this in relation to this muscle is contrary to the data available in literature, which reports that larger masticatory muscles occur in individuals without dentofacial pathologies (Ariji et al., 2000).

The comparison of the components of mandibular skeletal structures among the classes revealed that the mandible in all its linear dimensions (ramus, body, total length) with high statistical reliability is substantially smaller in individuals with Skeletal Class II; this is in accordance with the data available in literature and often is defined as a retrusive or retrognathic mandible (Proffit and White, 2003). On the basis of these results, we can claim that in comparison to the individuals with Skeletal Class I or III, the individuals with Skeletal Class II have significantly smaller parameters of *musculus pterygoideus medialis* and the mandible.

Unfortunately, there are no equivalent researches covering and analysing all skeletal classes in one place. Dicker (2007) having analysed individuals with mandibular retrognathia in the population of Europe, reported that the parameter of volume of *musculus pterygoideus medialis* is 9.56 cm^3, and this is quite similar to the relevant parameter reported in this research, where in individuals with Skeletal Class II this parameter was 9.2 cm^3.

The spatial parameters of Class III muscles have been reported by authors who analysed individuals representing the population of China. Ariji et al. (2000), having covered a large pool of individuals in an MSCT research, reported that the cross-sectional area of *musculus masseter* is 3.7 cm^2 in Class I individuals and 3.18 cm^2 in Class III individuals, thus proving that with high statistical reliability Class I individuals have larger muscles. In this research a similar tendency is observed only in relation to the cross-sectional area of *musculus masseter*, which for the individuals of Class I is 4.9 cm^2, but the individuals of Class III is 4.5 cm^2, but not statistically significant. In comparison to Ariji et al. (2000), in this research the size of the muscles of the individuals of Skeletal Class III is larger, but in comparison to Kitai et al. (2002) significantly smaller in relation to the volume measurement.

When comparing the parameters of the normative group of this research (the volume of musculus masseter 22.7 cm^3 and the cross-sectional area of *musculus masseter* 4.9 cm^2) and the parameters of the normative group or Class I individuals without occlusion anomalies, available in literature, we concluded that the measurements greatly differ from the relevant data of Hsu et al. (2001) – 31.4 cm^3 and 6.3 cm^2 in individuals representing the population of China. A similar situation is regarding the relevant data of Goto et al. (2002) – 29.2 cm^3 and 5.5 cm^2 in Mongoloids, but Ariji et al. (2000) has reported that the cross-sectional area is 3.7 cm^2. The difference in results is likely to be related to morphological differences of Eurasians and Mongoloids or different methodological approaches. The difference in results is likely to be related to morphological differences of Eurasian and Mongoloid race or different methodological approaches.

Comparison among the horizontal, the neutral and the vertical growth type groups

The results of our research indicate that the largest parameters of *musculus masseter* and *musculus pterygoideus medialis* occur in individuals with the horizontal growth type, but the smallest parameters occur in individuals with a vertical growth type.

Only the parameters of the volume and the cross-sectional area of *musculus masseter* differ between the research groups with high statistical reliability: the largest muscles are observed in the horizontal group, and the smallest in the vertical group, which is consistent with several literature sources (Boom et al., 2008; Chan et al., 2008; Van Spronsen, 2010; Lione et al., 2013). The tendency observed in relation to the parameters of *musculus pterygoideus medialis* is similar to the tendency observed in relation to *musculus masseter*. It should be stressed that the difference remains only between the parameters of the horizontal and the vertical groups, but there is no statistical reliability among the parameters of the vertical and the neutral, and the neutral and the horizontal groups. On the other hand, Van Spronsen et al. (1992) having compared the masticatory muscles of only 35 individuals of the normal growth type group and 13 individuals of the vertical growth type group, concluded that the differences are moderate or small.

In this research the parameters of the volume and the cross-sectional area of *musculus masseter* in individuals with horizontal growth type is respectively 25 cm^3 and 5.1 cm^2, but when comparing these data to the data of literature covering individuals with similar craniofacial morphology, it can be seen that similar parameters are mentioned in the report of Boom et al. (2008), where these results respectively where 24.3 cm^3 and 5.1 cm^2, but Dicker et al. (2007), having analysed 12 orthognathic patients with reduced vertical dimension reported the relevant parameters to be 26.16 cm^3 and 6.6 cm^3, but Van Spronsen (2010) having analysed only the cross-sectional area reported it to be 6.22 cm^2 in individuals with the morphology of "short face", and that is approximately 1 cm^2 larger parameter for this group of individuals. We assume that the differences could be related to the criteria that were used for determining the craniofacial growth type in the vertical dimension, as well as to the aforementioned methodological factors.

Van Spronsen (1992) describes that *musculus masseter* and *pterygoideus medialis* are slightly smaller in individuals with vertical growth type morphology than in individuals of the normative group, but in this research a statistically significant difference remains only between the horizontal growth type group and the vertical growth type group, and only regarding the parameters of the volume and the cross-sectional area of *musculus masseter*.

4.4. Correlations between the spatial parameters of the masticatory muscles and the skeletal structures of the mandible

To carry out an in-depth analysis of the form-function interaction between the biomechanical load (potentially caused by the muscles) and the mandible, as well as the consequences of this interaction, and assuming that the mandible under various dentofacial deformities is loaded differently, the correlations were separately analysed in Skeletal Classes I, II, III and in the neutral, horizontal, and vertical growth type groups.

Skeletal Classes I, II and III

The ANB parameter was established as a criteria for determining the severity degree of dentofacial deformities in the sagittal plane. The analysis of all the groups together revealed statistically significant and strong negative correlation between the ANB parameters and the volume of *musculus pterygoideus medialis*; this indicates that the more severe the Skeletal Class II is, the smaller the mentioned muscle.

The correlations between both muscles and the components of the mandible in Skeletal Classes I, II, III are inconsistent. One similar association tendency in all the groups is not observed. Better (stronger), more frequent and statistically more significant connections between the components of the masticatory muscles and the components of the mandible were observed in the Skeletal Class I (normative). Within the normative group there is evidence of strong and statistically significant correlation between the parameters of *musculus pterygoideus mediali* and the parameters of the ramus, the body and the total length of the mandible, and medium strong but statistically significant correlations between the parameters of *musculus masseter* and the parameters of the ramus, the body and the total length of the mandible. In other groups the correlations are similar to those mentioned above, but weaker and statistically less significant.

When seeking connection between the volume of the masticatory muscles and *zygomatico-mandibular* in individuals with Skeletal Class III, Kitai et al. (2002) discovered well pronounced correlation that was not observed in this research.

Van Spronsen et al. (1999) researched normative adults and analysed connections between several masticatory muscles and the parameters of craniofacial morphology, but did not find any significant and regular correlations, which contradicts this research where significant correlations between the linear measurements of both muscles and the measurements of the mandible were observed, particularly among the individuals of Skeletal Class I (normative).

In our research, we observed a well-pronounced tendency that the parameter of volume correlates more often and with higher statistical reliability than the parameter of cross-sectional area and thus indicates stronger connection to the components of the mandible.

In-depth analysis of the connections and regression revealed that dentofacial deformities whose severity in the sagittal plane is up to 58 % may be influenced by the volume of *musculus pterygoideus medialis* and the total length of the mandible that statistically reliably forecasted the ANB angle. The contribution of *musculus pterygoideus medialis* can be considered as significant; however, other potential influential factors, not analysed in this research, should be taken into account.

Horizontal, neutral and vertical growth types

The analysis of all the groups together revealed statistically significant and strong negative correlation among the MS-SN parameters and the volume and the cross-sectional area of *musculus masseter*, as well as the volume of *musculus pterygoideus medialis*, and this establishes that the increase in the vertical dimension of the face means the reduction of the parameters of the muscles; i.e. the individuals with long-face morphology (vertical growth type) have weak masticatory muscles and opposite manifestation can be seen in individuals with short-face morphology (horizontal growth type). This finding is in line with several earlier reports (Lione et al., 2013; Benington et al., 1999; Chan et al., 2008; Boom et al., 2008), but contradicts to the findings of Kitai et al. (2000), who did not observe any connection between the *gonial* angle and the volume of *musculus masseter*.

In various growth groups, irregular correlations between both muscles and the components of the mandible can be observed. Better, i.e. more frequent, connection between the components is observed in the neutral growth type group. *Musculus masseter* shows more pronounced connection – more frequent and stronger correlations than *musculus pterygoideus medialis*. This observation suggests that *musculus masseter* in the vertical dimension of craniofacial morphology is more sensitive to changes than *musculus pterygoideus medialis*; this is also confirmed by Van Spronsen (2010).

The parameter of volume clearly shows stronger connection with the components of the mandible contrary to the cross-sectional area; suggesting thinking of the relevant contribution of the manifestation of the physiological function of each morphological parameter. Boom et al. (2008) proved that the volume as a parameter is more significant and can be stronger associated with the craniofacial vertical dimension than the cross-sectional area; this is also confirmed in this research.

An opinion expressed in literature states that the individuals with wider transverse face dimension i.e., hypodivergent face type has stronger masticatory muscles (Kitai et al., 2002; Van Spronsen, 1991; Hannam and Wood, 1989; Weijs and Hillen, 1986). This was also proven in this research, where statistically significant and positive correlations between the transversal dimension of the mandible and the volume of *musculus masseter* were observed only in the horizontal growth type group.

In literature it is possible to find reasons explaining why the parameter of the cross-sectional area of *musculus masseter* shows stronger correlation with the components of the mandible, than the parameter of the cross-sectional area of *musculus pterygoideus medialis*; this phenomenon in this study is observed both in the skeletal classes and the growth type groups. Van Spronsen et al. (1997) in studies of the spatial orientation of the masticatory muscles discovered that *musculus pterygoideus medialis* in relation to the middle-sagittal plane in average is inclined by an angle of 22.8°, and if the measurements of it are carried out in the axial plane, direct measurement is impossible and over-measurement of this muscle is unavoidable. This explains why the correlations are weaker and less frequent, in comparison to *musculus masseter*.

Also, the observation according to which the measurement of the cross-sectional area (contrary to the measurement of the volume) indicates weaker and less frequent correlations with the components of the mandible could be explained with the fact that this parameter characterizes the maximum force developed by the muscle in average for 6 minutes during 24 hours only (Miyamoto et al., 1996), and therefore the overall influence of this parameter can be weaker.

In-depth analysis of the connections and regression revealed that dentofacial deformities whose severity in the vertical plane is up to 37 % may be influenced by such variable values as the volume of *musculus masseter* and the total length of the mandible, the height of the ramus of the mandible, and the length of the body of the mandible that statistically reliably forecasted the MP-SN angle.

The regression analysis explains significant influence of *musculus pterygoideus medialis* and the total length of the mandible on the severity degree of the dentofacial deformity in the sagittal plane, but moderately pronounced influence of *musculus masseter* and all the analysed linear components of the mandible on the degree of severity of the dentofacial deformity in the vertical plane. It should be taken into account that there are also other biological factors that might influence dentofacial deformities in all planes; and theoretically such factors could be the architecture of the muscle fibres, the spatial orientation of the muscles against the temporo-mandibular joint, the potential of the bone adaptation to the applied forces, which could be studied in the future.

5. CONCLUSIONS

1. The methodology of MR and CBCT developed for this study can be assumed as reliable (based on error analysis) and applicable in equal studies in future.
2. The volume parameter of *musculus pterygoideus medialis* in the sagittal plane substantially differs among the Skeletal Class I, II, and III, but the parameter of volume and the cross-sectional area of masseter significantly differ among the craniofacial growth type groups.
3. Skeletal Class II individuals unlike the individuals with Skeletal Class III, have significantly smaller parameters of the volume of *musculus pterygoideus medialis* and significantly smaller all the parameters of the mandibular skeletal structures.
4. The individuals with the vertical craniofacial growth type, unlike the individuals with a horizontal growth type, have significantly smaller parameters of the volume and the cross-sectional area of *musculus masseter.*
5. The correlations found in the groups of Skeletal Classes I, II, III and in the horizontal, neutral and vertical growth type groups, are inconsistent, without one single significant pattern; this suggests a connection between the various consequences of biomechanical activity and the nature of the load (as a mutual interaction), and the variability of the skeletal structures of dentofacial deformities.
6. In the neutral craniofacial growth type group and Skeletal Class I group (the normative group), correlations between the structures of the muscles and the structures of mandible are more frequent, stronger, and statistically more significant. This suggests a higher probability that the form-function relations are significant for mutually harmonious development of structures, contrary to the dentofacial deformation groups.

7. Volume as the biomechanical characteristic seems to be more significant parameter for the craniofacial area than cross-sectional area.
8. The connection between the spatial parameters of *musculus masseter* and *musculus pterygoideus medialis,* and the variations of the mandibular skeletal structures has only partial influence on the severity degree of dentofacial deformities in the sagittal plane and vertical plane.
9. *Musculus masseter* is more sensitive against any variations and has more significant influence on the craniofacial vertical dimension, but *musculus pterygoideus medialis* has more significant influence on the sagittal dimension.

6. PRACTICAL RECOMMENDATIONS

1. We recommend the MRI methodology of this study for specialists of orthodontics, orthognathic surgery and radiology to include in the process of guideline and practical recommendation preparation.
2. We recommend the methodology and results of this study to include in the post graduate education programs for the students of orthodontics and radiology.

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