

Original articles

Relationship of the thickness and electric activity of the masseter muscle with bite force: a morphological and electrophysiological study

Relação da espessura e da atividade elétrica do músculo masseter com a força de mordida: um estudo morfológico e eletrofisiológico

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Conflict of interest: non-existent

ABSTRACT

Purpose: to study the relationship of thickness and electrical activity of the masseter muscle with the bite force.

Methods: the study included 17 young adults (21.3 ± 1.4 years), 7 female and 10 male, healthy and clinically asymptomatic, as temporomandibular disorders. It was performed to measure the thickness of the masseter muscle unilaterally during rest and maximal voluntary contraction. It was also quantified the bite force for each side with a force transducer positioned in the first molar region and simultaneously, it was assessed the electrical activity of the masseter muscle during the unilateral bite. The analysis was based on the comparison of samples, and used the t test, Wilcoxon, Mann-Whitney and multivariate linear regression.

Results: the thickness of the masseter muscle was greater in men than in women, both at rest and in contraction. We found symmetry between the sides with the muscles at rest and during contraction. The median frequency of the electromyographic signal to the masseter muscle in maximal voluntary contraction, showed no statistically significant difference intra-individuals and the comparison between the genres. We found a higher bite force in males. It was not found a multivariate linear regression model between variables.

Conclusion: in this study, it was not possible find a linear model with the variables studied.

Keywords: Masseter Muscle; Bite Force; Ultrasonography; Electromyography

RESUMO

Objetivo: estudar a relação da espessura e da atividade elétrica do músculo masseter com a força de mordida.

Métodos: participaram do estudo 17 adultos jovens ($21,3 \pm 1,4$ anos), sendo 7 do gênero feminino e 10 do gênero masculino, saudáveis e clinicamente assintomáticos, quanto a disfunções temporomandibulares. Foi efetuada a medida da espessura do músculo masseter unilateralmente, durante o repouso e contração voluntária máxima. Também foi quantificada a força de mordida para cada lado com um transdutor de força posicionado na região do primeiro molar e simultaneamente avaliou-se atividade elétrica do masseter durante a mordida unilateral. A análise foi baseada na comparação das amostras, sendo utilizados o test t, Wilcoxon, Mann-Whitney e regressão linear multivariada.

Resultados: a espessura do músculo masseter foi maior nos homens, tanto no repouso quanto em contração. Observou-se uma simetria entre os lados com os músculos em repouso e em contração. A frequência mediana do sinal eletromiográfico, para o músculo masseter em contração voluntária máxima, não apresentou diferença estatisticamente significativa intra-indivíduos e na comparação entre os gêneros. Foi encontrada maior força de mordida nos indivíduos do gênero masculino. Não foi encontrado um modelo de regressão linear multivariada entre as variáveis estudadas.

Conclusão: neste estudo, não foi possível encontrar um modelo linear com as variáveis estudadas.

Descritores: Músculo Masseter; Força de Mordida; Ultrassonografia; Eletromiografia

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INTRODUCTION

The masseter muscle is an important component of the stomatognathic system, being one of the major muscles related to the bite^{1,2}. Due to its morphological constitution and important participation in mandibular kinetics, it can be considered one of the basis of the stomatognathic system³. Furthermore, researchers suggest that the masticatory muscles influence craniofacial skeleton, and might contribute to the definition of its morphology⁴.

The ultrasonography (USG) is a precise method that allows the quantification of the masseter muscle thickness *in vivo*⁵, a parameter that has been associated with the craniofacial morphology⁶⁻⁹, with the electrical activity,^{6,10,11} and with the differences between male and female individuals^{7-9,12}. The morphological differences of the masseter muscle have also been studied during relaxation and contraction, analyzing different parts of the muscle^{10,13}.

Other researches have studied the relationship between bite force and the masseter muscle thickness¹⁴. Also, the relationship between bite force and electrical activity¹⁰. Bite force has been studied in healthy individuals with normal occlusion^{10,15}, which shows the researchers interest in bite force studies in order to functional assessment and monitoring of the stomatognathic system.

In 1992 Bakke *et al.*¹⁶ investigated the relationship of bite force and electrical activity of the masseter muscle with muscle thickness measured by ultrasound, besides the influence of occlusal factors and craniofacial characteristics, considering the masseter muscle thickness in three parts. Whereas Kim *et al.*¹⁷ in 1999 associated the electrical activity of the masseter and temporal muscles with bite force and haemoglobin concentration in the blood.

The superficial electromyography (EMGs) is a non-invasive electrodiagnostic method by which is possible to quantify the myoelectric activity¹⁸, through electromyographic parameters are obtained electrophysiological information from the muscle. The study of the frequency spectrum, more specifically the median frequency (Fmed) and the mean frequency (Fm) makes possible to identify the muscular fatigue¹⁹⁻²².

The Fmed is a parameter obtained from the electromyography signal that has been widely used in muscular fatigue studies. Researchers have observed that median frequency indicate the recruitment of specific types of muscular fibers, determining the predominance of slow or fast twitch muscle fibers²¹.

Other researchers carried out histomorphologic studies describing the fibers of the masseter muscle, correlating them with their electrophysiology^{21,23}.

The masseter is one of the main muscles responsible for mandibular movements and for bite force; which justifies the need of carrying studies out about this muscle. The thickness measurement by USG, and the quantification of myoelectrical activity by EMG are useful tools in non-invasive morphological and electrophysiological assessments. Associated with these methods, the bite force measurement can reveal important information about the development of therapeutic protocols.

It is possible that these variables reveal a linear relationship. Obtaining further clarification on the subject can contribute with new information about the muscular morphofunctionality and electrophysiology associated to the stomatognathic system, obtained by non-invasive methods. Thus, the purpose of this study is to investigate a possible existence of a linear relationship between masseter muscle thickness and its electrical activity with the bite force.

METHODS

This study has obtained Ethical approval to conduct the research of Research Ethics Committees (REC) of the Federal University of Pernambuco (UFPE), Center of Health Sciences (CCS), approval letter nº 776/2011, and approval registration REC nº 356/10.

Participated in the study 17 young adults volunteers (21.3 ± 1.4 years), 7 females and 10 males. All of the volunteers were clinically asymptomatic to temporomandibular dysfunctions (TMD) and had full dentition, disregarding the absence of the third molar. All volunteers were students of CCS at UFPE. This study draft was classified as descriptive, transversal and observational.

The assessment of the masseter muscle through ultrasound was carried out Hospital of Clinics at UFPE. The electromyographic evaluation and the bite force measurement were conducted in the Laboratory of Orofacial Motricity of the Department of Speech Therapy at UFPE.

The exclusion criteria were: clenching teeth signals or symptoms, bruxism, temporomandibular or neuromuscular disorders, being in orthodontic treatments or having any alteration in the stomatognathic system that compromises the evaluation, and develop gagging reflex during the evaluation of bite force.

Methodology of ultrasound assessment of the masseter muscle thickness

It was used a General Electric® ultrasound device model Logic 400, with a high frequency linear transducer of 10MHz, being taken three measurements of the masseter muscle in resting state, of the right and left sides. And then, three measurements in the maximal voluntary contraction (MVC) state for each side.

It was applied ultrasound conductive gel in order to eliminate the air space that forms between the transducer and the skin. This way, transmitting the ultrasonic waves directly to the tissue, avoiding waves reflection, which may occur due to the different acoustic impedances of means. Using the gel also facilitates sliding the transducer. To position finding and definition of the reference points during muscle thickness measurement, the transducer was handled perpendicularly through the superficial beam of the masseter muscle, while the volunteer performed teeth clenching, intended to gain a better visualization of the muscle limit. After image acquisition, it was performed to define the thickest muscle points. The image with high definition and that showed high reproducibility were considered to obtain the muscle thickness.

The medium region of the muscle, equivalent to the muscle belly, is perceived as the area with the most reproducibility⁵. The USG equipment allowed defining two points for muscular thickness measurement and expressing the value of the measurement in millimeters.

The same evaluator took all measurements. It was avoided the excessive pressure of the transducer over the muscular surface, in order to avoid possible interferences in the real value of muscle thickness. During the ultrasound, electromyographic and bite force evaluations the volunteers remained seated.

The ultrasound measurement was performed in MVC three times on right and left sides. There was a two minutes resting period between contractions in order to avoid muscular fatigue.

Simultaneous measurement of the masseter muscle electrical activity and bite force

The procedures were initiated with the preparation of the volunteers for placement of the electrodes responsible for signal capture. The preparation consisted in skin cleansing on masseter muscle area, using cotton slightly dampened in alcohol 70%. The male volunteers were previously instructed to shave before coming to the evaluation. Both procedures aimed to decrease the electrode contact impedance.

The electrodes placement on the muscular surface obeyed longitudinal orientation of the external beam of the masseter muscle, detected during the contraction state, by palpating the muscle. We used the disposable surface Ag/AgCl for ECG electrodes, Kendall®, Meditrace (Mansfield, Massachusetts, USA). The inter-electrode distance was standardized as 2 cm (center to center). A reference electrode was also used and positioned on olecranon of the ulna.

The electromyographic signal was captured using the acquisition module Miotool 400, 4 channels (Miotec®, Porto Alegre, Rio Grande do Sul, Brazil), with the acquisition software. During signal acquisition, a battery maintained the electromyograph running independently of the power line.

Miograph 2.0 software (Miotec®) was used in the acquisition with gain of 1000; 1000 points/second sampling rate; low-pass filter at 20Hz and high-pass filter at 500Hz; and during the analysis, a Notch filter was used at 59Hz-61Hz frequency to eliminate the possibility of interference from power line noise. The electrodes were connected to a preamplifier SDS 500 (Miotec®) that was connected to a signal acquisition module Miotool 400. The equipment was connected to a portable computer Acer® Aspire model 110-1564 with processor Intel® Atom, 1.6GHz clock frequency, 1GB RAM memory and 100GB hard drive.

Simultaneously electromyographic recording, it was performed the bite force recording, using a single load cell transducer, (Miotec®) whose characteristics are described in Figure 1, also connected to the signal acquisition module Miotool 400.

PARAMETER	VALUE
Output voltage (OV)	2mV/V nominal
Non-linearity	0.25% of OV
Non-repeatability	0.1% of OV
Maximum overload	150% of OV
Deflexion in inches	0.002 of OV
Working range of temperature	~15°C to 71°C of OV
Resistance between stations	350Ω Nominal

Figure 1. Technical specification of the bite force transducer.

Before bite force recording, the transducer was wrapped with plastic film made out of PVC (Dispafilm® from Brazil, Guarulhos, SP, Brazil). Then, it was wrapped with gauze (Megatex®, Recife, PE, Brazil), and taped with adhesive tape Micropore® 12,5 mm x 10 mm (3M®, Sumaré, SP, Brazil). The use of gauze aimed to help reducing the discomfort generated by the transducer during bite; this way, preventing dental injuries and facilitating transducer positioning between the teeth.

The load cell was positioned in the first molar region, and then the bite force was measured unilaterally. Simultaneously to that, the masseter muscle electrical activity was measured (Figure 2A, 2B). The measurements were taken three times in each side with two minutes intervals between bites to avoid muscular fatigue.

During evaluation, volunteers were in front of the computer monitor to have visual feedback of the bite force level and they were instructed by the evaluator to maintain contraction in the maximum value possible and steady (Figure 3).

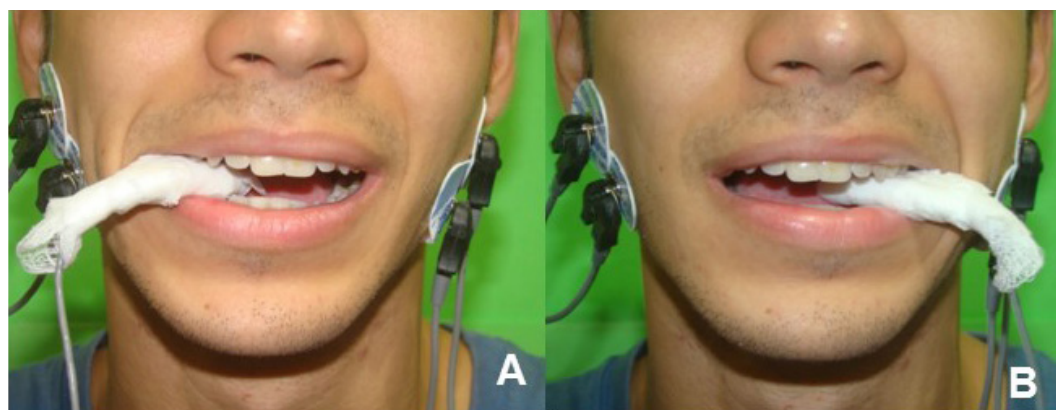


Figure 2. Positioning of the bite force transducer and the surface electrodes for detection of the electromyographic signal. Transducer in the right side (A); transducer in the left side (B).

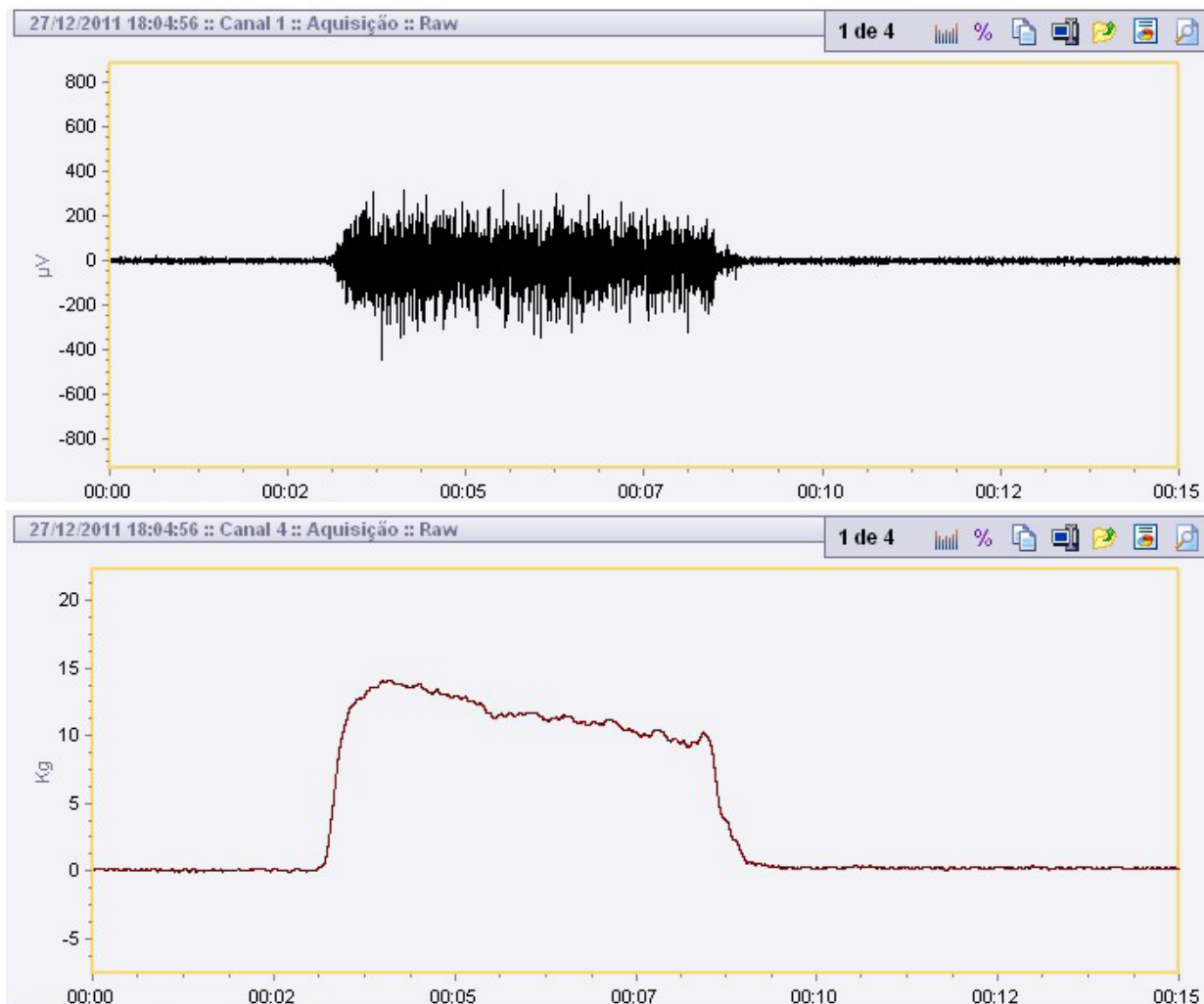


Figure 3. Electromyographic signal registered simultaneously with the bite force.

Analysis of the surface electromyography signal

After acquisition, the electromyographic signal was analyzed through normalized RMS (Root Mean Square) value. Normalization performed by the average of the ten highest peaks during each MVC. The median frequency was determined by the FFT (Fast Fourier Transform) of the three MVC values calculate the arithmetic average from the three tasks.

Statistical analysis of the data

The data was analyzed using RStudio software, Inc. v.0.99.441 (GNU General Public License) in a descriptive way, by either the mean and standard deviation or by the median. It was verified the homogeneity of variances for each variable and the normality of the data was verified using Shapiro-Wilk test. To investigate differences among results the following tests were used: student's t-test (for independent and paired samples), Mann-Witney and Wilcoxon (for paired

samples), according to normal distribution criterion to choose the application of these tests. The multiple linear regression was applied to the influence study of the independent variables over the dependent one (bite force).

In the linear regression, it is important to note that to promote increasing observations number, the data for both sides were added. Thus, obtaining a number of 34 observations, correspondent to 17 individuals.

RESULTS

In Table 1 the results are showed not considering the gender, for bite force, RMS value (μV), normalized RMS value (%). and median frequency of the EMGs signal of the masseter muscle. It is also showed the thickness of the masseter muscle during resting and contraction. It was not observed any statistically significant difference for any of these variables.

Local de inserção da tabela 1

Table 1. Descriptive statistics of the values and comparison of the sample in relation to the masseter evaluation (N=17).

		Average	Median	SD	p-value (R-L)
FORCE TRANSDUCER	Bite force (Kgf)				
	Right	17.76		9.67	0.676
	Left		12.92		
EMGs	Normalized RMS (%)				
	Right		38.10		0.309
	Left		39.67		
	RMS (μ v)				
	Right		99.57		0.651
	Left	112.80		52.38	
	Fmed (Hz)				
USG	Right	156.39		26.08	0.360
	Left	164.15		22.58	
	TMB (mm)				
	Right	15.62		2.18	0.931
	Left	15.55		2.34	
	TMR (mm)				
	Right	13.60		2.02	0.937
	Left	13.66		2.10	

Caption: DS (Standard Deviation); Fmed (Median Frequency); TMB (Thickness of the Masseter during Bite); TMR (Thickness of the Masseter during Rest) and USG (Ultrasonography). P-value (R-L), comparison of the right and left sides. Average and p-value for comparison with the non-matched t-test and median for the Mann-Whitney test, both tests referring to the comparison between sides.

Note: Average for comparison with test t and median for the Mann-Whitney; statistical significance ($p < 0.05$). The Mann-Whitney test was used since the analysis did not consider the distinction of individuals by gender.

Table 2 lists the results distributed by gender. Its analysis shows that the comparison of the studied variables, among the male individuals, did not show any statistically significant difference between sides. The same results were obtained from the comparison between the females' sides.

Still in table 2, it is possible to see that, among individuals from the masculine and feminine genders there was statistically significant difference in the bite force comparison, to the left side. Amongst male and female individuals there was statistically significant difference in the right side of the masseter muscle thickness during contraction. In the left side, the difference was also present; however, it was not statistically significant ($p\text{-value} = 0.053$).

During the resting period, the comparison of the masseter muscle thickness presented statistically significant difference amongst male and female individuals for both sides.

The masseter muscle thickness presented statistically significant difference at resting and contraction conditions for both genders, as can be seen on Table 3.

Model of multivariate linear regression

For the investigated sample, it didn't find a linear regression model with at least two of the studied variables, even with logarithmic transformation; the methods did not allowed the acquisition of an R^2 value with statistical relevance ($R^2 \geq 0.30$).

Table 2. Descriptive statistics and comparison of sample values in relation to the instruments of evaluation of the masseter, considering genre.

	Studied variables	Male (N=10)			Female (N=7)			pM	pF	p-value (M-F)
		Average	Median	SD	Average	Median	SD			
Force transducer	Bite force (kgf)									
	Right	20.45		11.15	13.90		5.78	0.311	0.174	0.177
	Left	21.76		10.80	9.92		2.45			
EMG	Normalized RMS (%)									
	Right	36.27		10.17	38.67		2.41	0.147	0.578	0.553
	Left	40.20		4.42		39.67				
	RMS (μ V)									
	Right		156.80			94.51		0.064	0.468	0.457
	Left	109.20		44.53	117.9		65.49			
	Fmed (Hz)									
	Right	159.69		23.15	151.66		31.06	0.606	0.065	0.549
USG	Left	163.04		25.28	165.72		19.89			
	TMB (mm)									
	Right	16.58		1.85	14.24		1.93	0.788	0.946	0.023*
	Left	16.45		2.24	14.26		1.94			
	TMR (mm)									
	Right	14.50		1.67	12.31		1.85	0.916	0.624	0.023*
	Left	14.52		1.73	12.42		2.07			

Caption: DS (Standard Deviation); TMB (Thickness of the Masseter during Bite); TMR (Thickness of the Masseter during Rest); p^M: (Comparison between sides for male individuals) and p^F (comparison between sides for female individuals). The p-value (M-F) is the comparison of the masseter muscle samples of the individuals between sides (i.e., right male - right female).

Note: Among individuals of the same genre, for the comparison of sides, it was applied the paired t-test (or Wilcoxon), obeying the criteria of normal distribution of the data in the application of the test. For the comparison between the masseter muscle of the female and male (i.e., the right side with the left side), it was applied the independent t-test (or Mann-Witney), considering the criteria of normal distribution of the data.

*Statistical significance ($p < 0.05$).

Table 3. Comparison of the thickness of the masseter muscle values in relation with the situations of contraction and rest, considering the gender.

MALE (n=20)				FEMALE (n=14)				
	Average	SD	¥p-value		Average	SD	Median	#p-value
Contraction	16.52		<0,000*	Contraction	14.25	1.8		0.000*
Rest	14.52			Rest			13.21	

Caption: Average for the Student's t-test* (for paired samples) and median for the Wilcoxon# test, for paired samples, obeying the criteria of usage of these tests;

*Statistical significance ($p < 0.05$); SD (Standard Deviation).

Note: Data added the observations for each side to compare the contraction state to the resting state.

Table 4. Displays the tested variables in the modeling of the multivariate linear regression (n=34).

TESTED VARIABLES
Bite force*
Median Frequency
RMS Value
Normalized EMG signal
Thickness of the masseter muscle in contraction
Thickness of the masseter muscle during resting

*Dependent variable.

Caption/RMS = Root Mean Square

EMG = Electromyography

DISCUSSION

Contrary to what we hypothesized, we could not find a significant association among bite force, electrical activity, and masseter muscle thickness measurements in young adults. The existence of a regression model would allow a better comprehension about the role of each variable in the estimation of the bite force.

The results from the comparisons among averages are in with other studies, regarding the thickness of the masseter muscle, being higher in men than in women^{7-9,12}. The literature also mentions that in male individuals the masseter muscle presents higher thickness, higher volume, greater area of the transversal section, and larger width than female individuals¹², in both contraction and resting^{8,9}. The fact that male individuals bite stronger may be related to a bigger transversal section of type II fibers²⁴.

Measurement results of the masseter muscle thickness found in this study are compatible with ultrasound measurements obtained by the area of the transversal section parameter, which it was also larger in male individuals ($4.3 \pm 1.5 \text{ cm}^2$) in comparison with female individuals ($3.0 \pm 1.2 \text{ cm}^2$). Furthermore, male individuals presented higher symmetry of the transverse section area²⁵.

In addition to the thickness being measured through USG, other studies have also verified masseter muscle morphometry by computerized tomography (CT)²⁶ and nuclear magnetic resonance (NMR)^{27,28}. It has been discussed that ultrasonography produces similar results to those obtained by NMR⁵. In this article, masseter muscle thickness values were higher for men, according to previous studies²⁹. The same results were found for the transversal sectional area³⁰, obtained through USG, when compared to female individuals.

It is already known that masseter muscle activities could also define its morphology, such as the

craniofacial morphology⁴. Based on the electrical activity study of the masseter muscle and the measurement of its thickness, some researchers have sustained for the idea that individuals with long craniofacial morphology have different masseter muscle morphology, compared to those with short face⁶.

A hypothesis that differences on the diet, such as eastern and western diets, could determine masseter muscle morphology, could be thought. However, this hypothesis seem be unsupported, as shown in the comparison between one study carried out in Sweden and other in China. In the Swedish study, the male individuals showed thickness of 9.7 mm and 15.1 mm, during resting and contraction respectively; whereas the female individuals showed thickness of 8.7 mm and 13.0 mm, during resting and contraction respectively⁹. In the Chinese study, the male individuals showed 11.83 mm and 15.51 mm, during resting and contraction respectively; whereas the female individuals, showed 9.84 mm and 13.02 mm, during resting and contraction respectively⁸.

The current study results of masseter muscle thickness (Table 2), show small difference when compared to the studies mentioned previously mentioned. However, we need to take in consideration that Brazilian diet is different from the participants' diets in those studies. Once food consistency seems to have an influence on the craniofacial development and more specifically in the mandibular condyle³¹.

In this article, the masseter muscle thickness of the same gender individuals (Table 3) differs statistically significant ($p < 0.05$) when contracting and resting, as described in the literature²⁹.

The masseter thickness in contraction state and in resting state showed symmetry between sides (Table 2). This indicates that the study was able to control possible methodological errors, such as dental

conditions and possible neuromuscular disorders associated with the temporomandibular disorders (TMD).

The median frequency, obtained in this study, didn't intend to determine muscular fatigue, because the tasks were of a short duration, including a resting interval. The aim was to study the electromyographic parameters, relating them with bite force and muscular thickness.

Regarding EMG signal amplitude, it's already described that increasing effort intensity generates an increase in the RMS value. However, it entails a decrease in the median and mean frequency value over time³². This variation has been used in muscular fatigue studies and in fiber recruited type studies during specific tasks. In the distribution of the spectral frequency, the median frequency of the EMG signal tends to move toward smaller frequencies values^{21,33} as muscle initiate fatigue. Researchers believe that there must be a link between the median frequency decreasing and the decrease in conduction speed of action potentials composing the EMG signal²¹. It is possible that the muscle spectrum frequency varies depending on the existence of a resting interval or on the bite duration. Moreover, it is also possible that the muscle area, where the signal is generated and captured, affects the value of the median frequency of EMG signal; in other words, the fibers of the superficial beam or the deep beam might interfere with the value of the median Fmed. It's also known that under sustained contractions the masseter muscle shows smaller values of median frequency than the temporal muscle^{21,33}.

According to the literature the bite force has been measured unilaterally^{24,34}, and bilaterally^{34,35}. Some researchers found that the bite force and the electrical activity of the masseter muscle and the temporal muscle were smaller when measured unilaterally than when measured bilaterally³⁴. Throughout the methodology development of this study, it was observed that there was high difficulty to perform the bite force bilaterally evaluation. Therefore, we choose to measure unilaterally. Also, we choose to perform MVC in short duration in order to prevent muscular fatigue in the volunteer.

A study analyzed the bite force, body mass, and physical conditioning of male soldiers indicating higher values for bite force after training in the army for three months. The results suggested that increasing physical activity may have influenced the high bite force values after the training³⁶.

During ordinary activities, the male individuals generally do physical activities that demand more effort in comparison to female individuals. It is possible that in the daily routine physical activity is a determining factor for male to present a higher bite force when compared to female.

Other fact that might be relevant, men gain muscle mass more easily than women do. Researchers consider that this fact might be associated with hormonal aspects, because men have high testosterone level³⁷. In addition, the intensity of the bites during mastication, and also the amplitude of the movement, might be another determining factor for greater bite force in males. The combination of these factors mentioned can suggest an influence in the values variability of the studied parameters, making it difficult to create a statistical model of linear regression.

Further studies are necessary to verify whether improvements in the performance of the bite force are related to increases in thickness and electrical activity of the masseter muscle. Additionally, whether physical activities influences in the thickness, bite force, and electrical activity of the masseter muscle.

Japanese researchers verified that the bite force seems to have different levels in children with primary dentition at different ages. The children of the feminine gender between 3 to 5 years of age seemed to have greater bite force than those of the masculine gender. Children of the masculine gender between 6 and 11 years of age, young teenagers at 12 to 14 years of age, and also teenagers between 15 to 17 years of age, seem to have greater bite force than females at the same age³⁸. This can suggest a relationship between higher testosterone levels in males individuals starting in the teenagers years.

Furthermore, it has been suggested males have a higher oxygenation rate and hemoglobin levels than females; in other words, there is a difference in hemoglobin oxygenation rate between genders³⁹. This fact can partially justify why males have a higher generation of bite force, greater thickness in MVC and a higher electrical activity of the masseter muscle.

In this study and in previous researches by different authors, it was note found a linear regression model associating bite force and craniofacial morphological measurements in men and women²⁴.

Other researchers, also by multivariate linear regression tried to relate the amplitude of the EMG signal to the morphological and histological factors (muscular fibers types) of the masseter muscle, in addition to

occlusal factors. It was found linear models with coefficient of determination from moderate up to strong level, one of these models included bite force and the masseter muscle thickness during resting ($R^2=0.55$)³. Other study found a model with the thickness of the masseter muscle in contraction (dependent variable) and craniofacial variables (independent variable), with correlation coefficient of moderate to strong level ($R=0.78$) and another model with the thickness of the masseter muscle during resting (dependent variable) and craniofacial variables at the same level ($R=0.78$)⁷. Comparisons between this study and those cited studies become more complex because of the same nature variables were not taken in consideration by the other studies. However, the lack of a model obtained through multivariate linear regression suggests that the independent variables outlined in Table 4 have little power of prediction regarding the value for bite force.

A linear regression model was not found for the studied sample. But, a scientific contribution of this study was the use of the multivariate linear regression. The study of new regression models using others EMG parameters can aid finding a linear relationship between variables.

Considering the central limit theorem, a bigger sample would find a better-defined pattern for the studied parameters, because of the variance homogeneity between data.

A statistical relationship would be found by gender analysis, combining a bigger sample size, controlling variables facial type and occlusion type, and applying multivariate analysis between the parameters involved in the study. More studies are needed to investigate the relationship between bite forces, spectral characteristics of the electromyographic signal (F_{med} and F_m), and ultrasound parameters of the masseter muscle (volume, transversal section area, thickness, width, and length).

Furthermore, a more detailed spectral analysis of the electromyography signal is needed, such as a specific study about activation of the superficial and deep beams. In order to decrease variance among the results of the studied parameters, in the future instead of using a MVC we suggest that use a established bite force and equal values for all volunteers

Individuals can perform different levels of muscular contraction. Because of that, predetermined standard measurements of contraction could be set to minimize possible methodological difficulties related to the contraction intensity in new studies. These standards

could be set by using dynamometer or bite force transducer, and the volunteer would monitor it as feedback. Thus, ensuring a uniform contraction level to all volunteers. Because the force transducer position on tooth is a factor that can interfere capturing bite force, studies about this factor are necessary.

Likely, by regression modeling, bite force influence would turn to be smaller than the influence of the EMG signal amplitude. This is due to the fact that biting the transducer is uncomfortable, causing a difference in the volunteers' performance. Besides that, the EMG recording appears to be more precise and specific. For these reasons, we suggest that future studies establish gradual levels of bite force.

The bite force is a difficult parameter to be measured because it is related to the occlusion and dental conditions. However, difficulties were not faced while measuring electromyographic parameters, related to muscular contraction, and ultrasound parameters, related to muscular morphology. The bite force measurement is limited to toothed groups of individuals and depends on the methodological positioning. Also, this measurement is dependent to preparation of the transducer between the superior and inferior teeth and the interdental forces. There's a possibility that variations on transducer position between teeth register different intensities values.

CONCLUSION

We hypothesize that it was possible to obtain bite force values from the masseter muscle thickness and electromyographic parameters as predictive variables. However, throughout this study we showed that this could not be obtained. In conclusion, new studies are required for further development.

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