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Original Article

Type of Correlation between Bite Force and EMG Activity of the Temporalis and Masseter Muscles during Maximal and Submaximal Clenching

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Abstract

Introduction: Maximal bite force is an important determinant of masticatory function and is essential for the estimation of dental status. Bite force is usually measured by gnathodynamometry.

Aim: The aim of the study was to investigate the type of correlation between the electromyographic activity of the masticatory muscles and the bite force during simultaneous measurement and to evaluate the use of EMG activity as an option for indirect determination of the bite force.

Materials and methods: The study included 68 people (33 men and 35 women) with a mean age of 18.4±6.1 years. The bite force and the sEMG were measured in all 68 subjects consecutively on the right and the left side during maximal (1) and submaximal (2/3 and 1/3) clenching. Statistical analysis was performed by IBM SPSS Statistics, version 23.0.

Results: EMG activity and maximal bite force values did not show significant differences on the left and right side. Linear relationship was found for the association bite force: EMG activity for the masseter muscle during maximal and submaximal (2/3) clenching, while for 1/3 clenching force the association was lost. For the temporalis muscle, this relationship was linear for the left side during maximal and submaximal 2/3 clenching and non-linear for the right side. During 1/3 clenching, the linearity was lost on both left and right sides.

Conclusions: The masseter muscle shows stable linear relationship between BF and EMG on both sides and can be considered reliable for indirect estimation of the bite force by measuring the EMG potentials. During low occlusal forces (1/3) the linearity of both masseter and temporalis muscles is decreased or lost.

Keywords

bite force, masticatory muscles, surface electromyography, type of correlation

INTRODUCTION

The evaluation of bite force is important for the estimation of the masticatory system in physiological and pathological conditions (temporomandibular disorders, bruxism, etc.) and the effects of treatment. The chewing muscles create sufficient bite force to provide normal masticatory function.[1] Gnathodynamometry (GDM) is the most commonly used method for measuring bite force (BF), and surface electromyography (sEMG) is used to measure the electrical activity of the jaw-elevator, masseter, and temporalis muscles. Direct BF measurement is appropriate for measuring submaximal forces; however, during maximal clenching, there is a risk of tooth fracture, pain, discomfort, or technical limitations of the instrument, such as inaccuracy during high loading. Surface electromyography is a safe and reliable method for evaluating muscle activity in both adults and children[2,3], and it is widely used to study the stomathognathic system in health and disease by monitoring the jaw-closing and facial muscles[4,5]. Some authors investigate the reproducibility of bite force and EMG activity as separate parameters[4], whereas others assess the relationship between bite force and EMG. According to some researchers, it can be used in mathematical modeling of jaw mechanics.[5] Due to a number of factors such as different sample sizes, direction of the bite force, various devices used, the reliability of this relationship is limited. So, the reproducibility of EMG activity in relation to the bite force of the masticatory muscles is largely unknown.[1] Gonzalez et al. evaluated the reliability of EMG activity in relation to the static bite force by testing different biting positions on molars and incisors, and recording the sEMG activities of the temporalis, masseter and suprahyoid muscles bilaterally. The linearity of EMG activity versus bite force was evaluated and data exist that the observed slope depends on the biting location and direction. [6] Gonzalez et al.[5] reported high reliability of the relationships concerning the masseter and temporalis muscles, and the reliability was higher for molar biting than incisor biting tasks. As for the suprahyoid muscles, the results were more variable for both molar and incisor biting site and often failed to achieve the criteria for reliability, which is explained by the variabilities of the buccal-lingual inclination of the incisors. Therefore, when evaluating the bite force to EMG ratio, it is recommended that the sensors be placed on the premolars to achieve greater reproducibility of the results.[5] The less reliable data from the suprahyoid muscles reflect the relatively small slopes of these muscles' EMG activity versus bite force relationships during static biting. As different approaches are used to evaluate the bite force, it is difficult to estimate the experimental results and unify them. Some authors[7] used a U-shaped force meter with the load cell positioned unilaterally between the first molars and used visual feedback to control tooth clenching; others measured incisal bite forces.[8,9] Many researchers consider that positioning the sensor on the first molars gives reliable and reproducible results of the bite force measurement.[5] Some researchers determine the relationship of bite force to EMG activity of the masticatory muscles during maximal clenching, while others investigate this relationship during submaximal clenching as well.[7,10] As a result of the various experimental protocols used, it is difficult to determine the type of bite force-EMG activity relationship.

AIM

The aim of the present study was to evaluate the type of relationship between bite force and EMG activity of the masticatory muscles during maximal and submaximal clenching bilaterally and to determine a reliable protocol for evaluating the occlusal forces in physiological and pathological conditions.

MATERIALS AND METHODS

The study included 68 healthy subjects (33 male and 35 female) with mean age of 18.4±6.1 years. The bite force and the surface EMG were measured simultaneously on the right and on the left side. Individuals who had undergone or were undergoing orthodontic treatment, or who had evidence of bruxism, were not included in the study. The inclusion criteria were: no temporo-mandibular disorders; no pain during clenching the teeth; no missing teeth in the lateral areas and no evidence of an acute inflammatory process.

Assessment of bite force

The bite force was measured by a strain-gauge transducer – a GD500.1 gnatodynamometric system with a test range of 0-700 newtons. The subjects sat on the dental chair with their heads upright in natural position and unsupported. The horizontal planes of the gnathodynamometer were positioned in the area of the first permanent molars. A maximal voluntary clench was performed on the fork of the strain-gauge transducer. After recording the maximal value - 1, the subject was asked to bite with 2/3 and 1/3 of the maximal bite force and these attempts are recorded. The subject observed the display and applied the necessary strain for 3 seconds. The measurement was taken bilaterally, sequentially to the left and right side at an interval of one minute, simultaneously with the recording of the EMG potentials of *m. masseter* and *m. temporalis*.

Assessment of EMG activity of the masticatory muscles

The surface EMG recording was performed using a two-channel electromyograph (Neuro-EMG-Micro-2) with the Neuro-MEP-Ω software. The electrical potentials of temporalis anterior (TA) and the masseter muscle (MM) were measured. Before placing the surface electrodes (Ag/AgCl), the skin was cleaned with 90% ethyl alcohol over the most prominent part of the muscle palpated in contraction, parallel to the fibers according to the Surface EMG for Non-Invasive Assessment of Muscles (SENIAM) program guidelines. All subjects were briefed on the procedure prior to the sEMG measurement. Maximal and mean EMG activity values of every contraction of the right and the left masseter and the anterior temporalis were recorded during maximal (1), 2/3 and 1/3 of the maximal bite force during a 3-second period. The EMG potentials were recorded in microvolts (μV). All participants gave their informed consent.

Statistical analysis

The statistical analysis was performed using IBM SPSS Statistics version 23.0. The Kolmogorov-Smirnov test was used to check the normality of distribution. Nonparametric tests were applied to variables that did not have a normal distribution. Regression analysis was used to find out what equation describes most precisely the type of association between the bite force and EMG activity of the masticatory muscles during maximal and submaximal force (1, 2/3, 1/3). All statistical tests were performed at a level of 5% for significance at $p<0.05$.

RESULTS

Table 1 shows the values for the bite force and EMG during maximal and submaximal clenching on the left and right side.

There was no significant difference between the left and right side of the bite force and the EMG activity of the temporalis and masseter muscles. The EMG values of the temporalis muscle were higher than those of the masseter muscle but without statistical significance.

Type of association between bite force and EMG potentials of the temporalis and masseter muscles during maximal clenching

On the right

The applied regression analysis and procedure 'Curve estimation' of SPSS found an association between the maximal BF and EMG potential of the right masseter muscle (RmMax), described best with the linear model (p=0.002, R^2=0.136) with the following parameters: BF=285,042+0.086*RmMax. The curve described a linear relationship. For the mean values, the linear model was (p=0.001, R^2=0.158) with the following parameters BF=152,744+0.799*RmMean. A directly proportional linear relationship was found, stronger for the mean values.

The relationship between BF and EMG activity of the right *m. masseter* (Rm Max, Rm Mean) during maximal clenching is shown in **Fig. 1**.

Fig. 2 shows the relationship between BF and EMG activity (max and mean values) of the right *m. temporalis* (RtMax; RtMean) during maximal clenching.

The association was best described by the reciprocal model (p<0.001, R^2=0.247) with the parameters: BF=575,579−176051,864/RtMax. The type of relationship was not linear. For the mean values of EMG of the right

Table 1. Bite force and maximal and mean EMG values of the masseter and temporalis muscles on the right (RM, RT) and left (LM, LT) side

BF	BF right	RM max	RM mean	RT max	RT mean	BF left	LM max	LM mean	LT max	LT mean
1	362.5±134.1	914.5±516.8	272.9±89.5	940.3±368.4	282.2±63.1	396.3±128.1	830.3±320.5	286.1±83.2	877.0±274.9	274.7±55.2
2/3	263.1±114.8	678.2±338.6	225.8±51.3	791.6±390.9	244.9±51.1	286.5±111.7	684.9±264.8	234.6±50.7	716.5±250.5	242.0±48.2
1/3	174.6±113.8	528.5±282.6	205.9±61.8	642.8±309.3	220.5±57.1	202.9±125.4	537.4±239.9	200.9±52.2	590.9±261.5	217.8±52.9

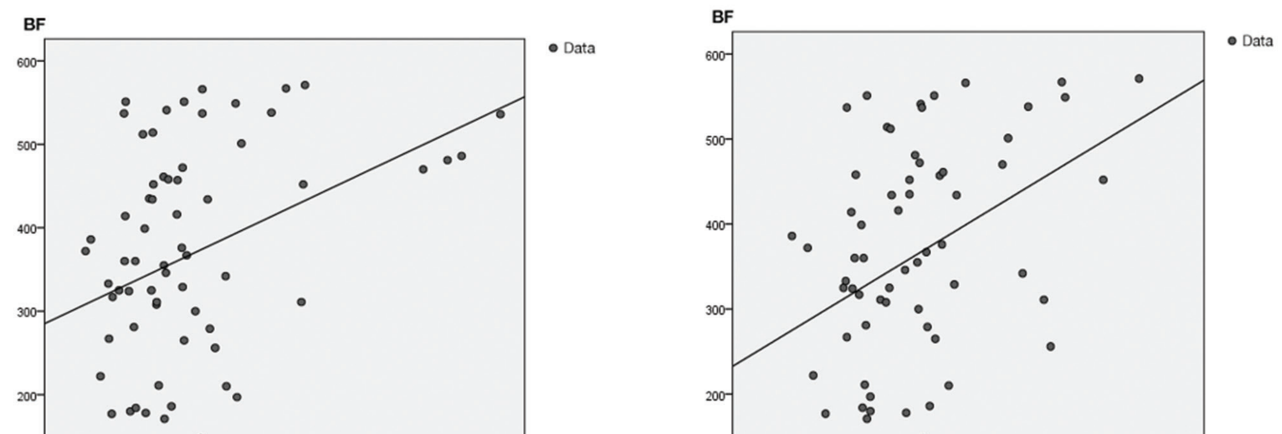

Figure 1. Type of correlation between BF and maximal and mean EMG values of the right masseter muscle.

temporal muscle, the association was described by the reciprocal model ($p<0.001$, $R^2=0.355$) and parameters: BF=753,097−105063,520/RtMean. The association is directly proportional but not linear.

On the left

The correlation between BF and EMG of the left masseter muscle during maximal clenching was described by the linear model ($p=0.001$, $R^2=0.154$) with parameters BF=271,966+0.131*LmMax for the maximal values and with the linear model ($p<0.001$, $R^2=0.186$) with parameters BF=205,701+0.665*LmMean for the mean values. The relationship is directly proportional and linear **(Fig. 3)**.

For the temporalis muscle, the relationship was described by the linear model ($p<0.001$, $R^2=0.331$) with the parameters BF=160,675+0.268*LtMax for the maximal values and by ($p<0.001$, $R^2=0.383$), and BF=−39.409+1.594*LtMean for the mean values respectively **(Fig. 4)**. The correlation is directly proportional and linear, and is expressed stronger for the mean EMG values of the left temporalis muscle.

Correlation between bite force and the EMG activity of the masticatory muscles during submaximal (2/3 max) clenching

On the right side

Because the values of the bite force were not normally distributed, they were logarithmically transformed (Ln) to be normalized. The relationship EMG of the right masseter/bite force was best described by the linear model ($p<0.001$, $R^2=0.180$) with parameters Ln(BF)=4,411+0.001*RmMax for the maximal values and with the logarithmic model ($p<0.001$, $R^2=0.235$) with parameters

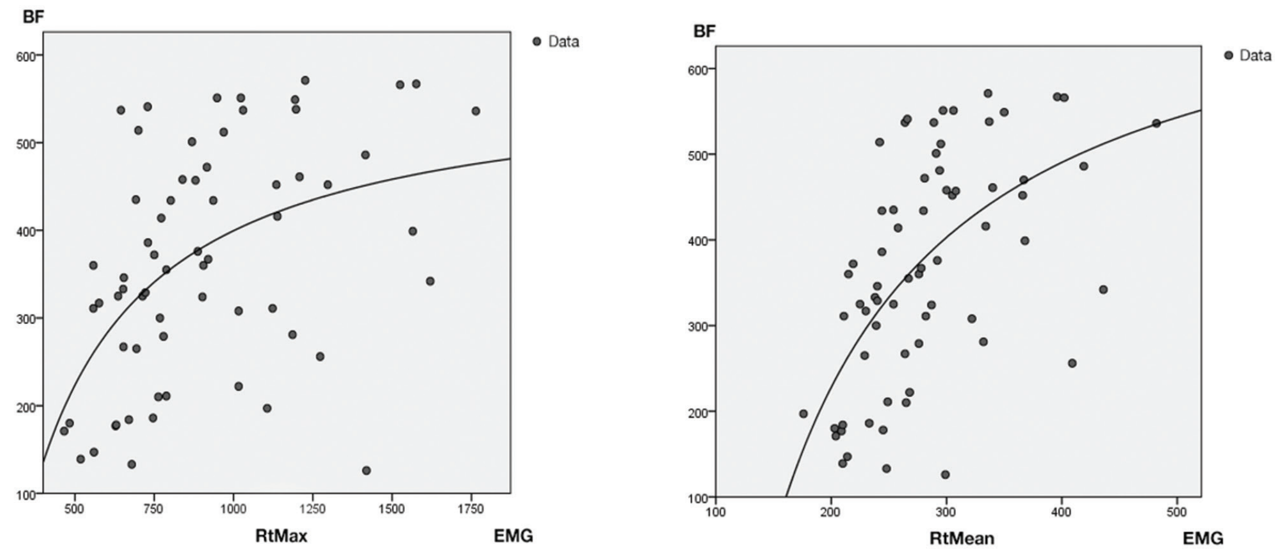

Figure 2. Type of correlation between BF and maximal and mean EMG values of the right temporalis muscle during maximal clenching.

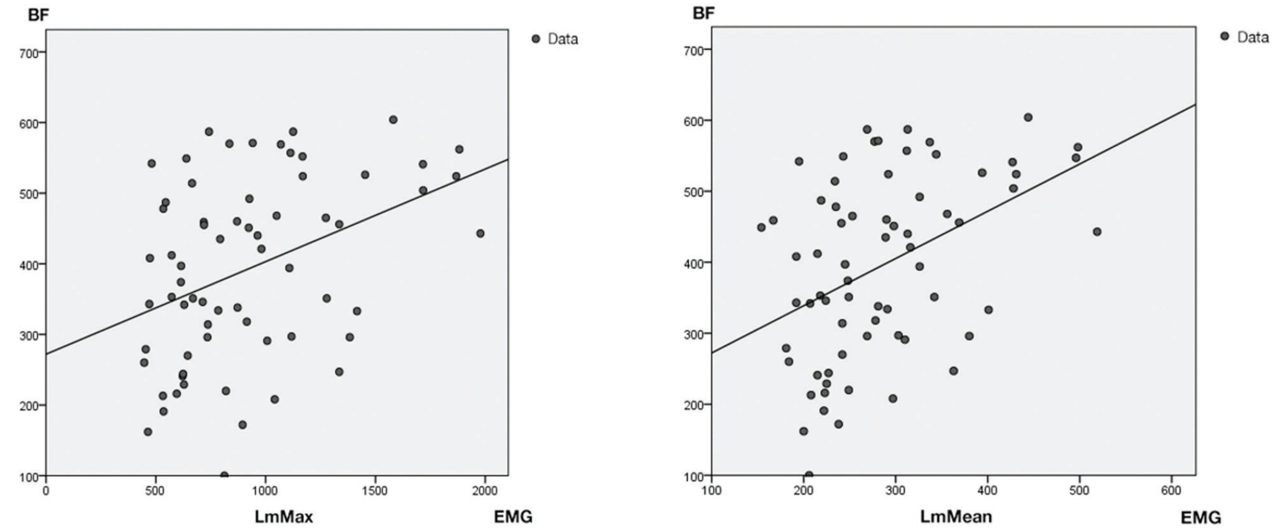

Figure 3. Type of correlation between BF and maximal (LmMax), and mean (LmMean) EMG values of the left masseter muscle.

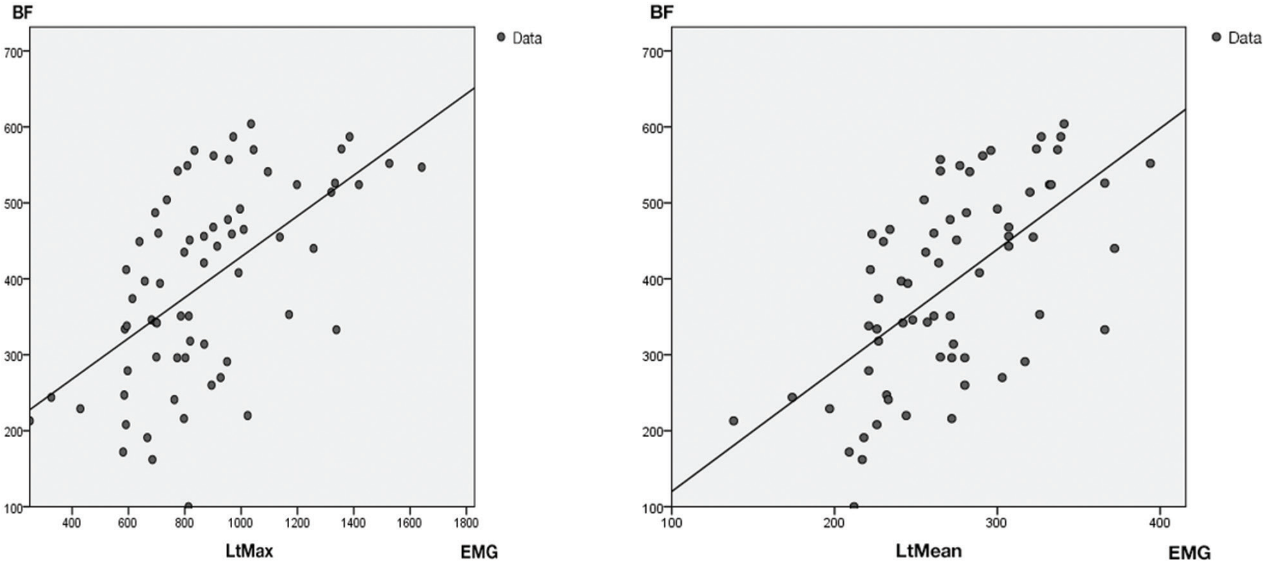

Figure 4. Type of correlation between BF and maximal (LtMax), and mean (LtMean) EMG values of the left temporalis muscle.

Ln(BF)=−2,061+(1.335*ln(RmMean) for the mean values. The curves for the right masseter are shown in **Fig. 5**.

For the right temporalis, the EMG/BF relationship during 2/3 max clenching is described best with the logarithmic model (p<0.001, R^2=0.431) with parameters Ln(BF)=−0.050+(0.792*ln(RtMax) for the maximal EMG values, and with the reciprocal model (p<0.001, R^2=0.467) with parameters Ln(BF)=6,849−389,725/RtMean for the mean values**.** The relationship has a directly proportional but not linear character **(Fig. 6)**.

On the left side

For the left masseter, the relationship is described best with the linear model (p<0.001, R^2=0.223) with parameters BF=69,329+0.238*LmMax for the maximal EMG values, and with the linear model (p<0.001, R^2=0.277) with parameters BF=−191.909+1,930*LmMean for the mean values. In both cases the relationship is linear **(Fig. 7)**.

For the left temporalis muscle, the relationship during 2/3 max clenching is described best by the linear model (p<0.001, R^2=0.432) with parameters BF=20,393+0.299*LtMax for the maximal values and by the linear model (p<0.001, R^2=0.509) with parameters BF=−188,236+1.778*LtMean for the mean values. The curves are shown in **Fig. 8** and have a linear relationship both for the maximal and mean values of EMG.

Correlation between bite force and the EMG activity of the masticatory muscles during submaximal (1/3 max) clenching

On the right side

Because the values of the bite force during submaximal clenching (1/3 max) were not normally distributed, they were logarithmically transformed to normalize them.

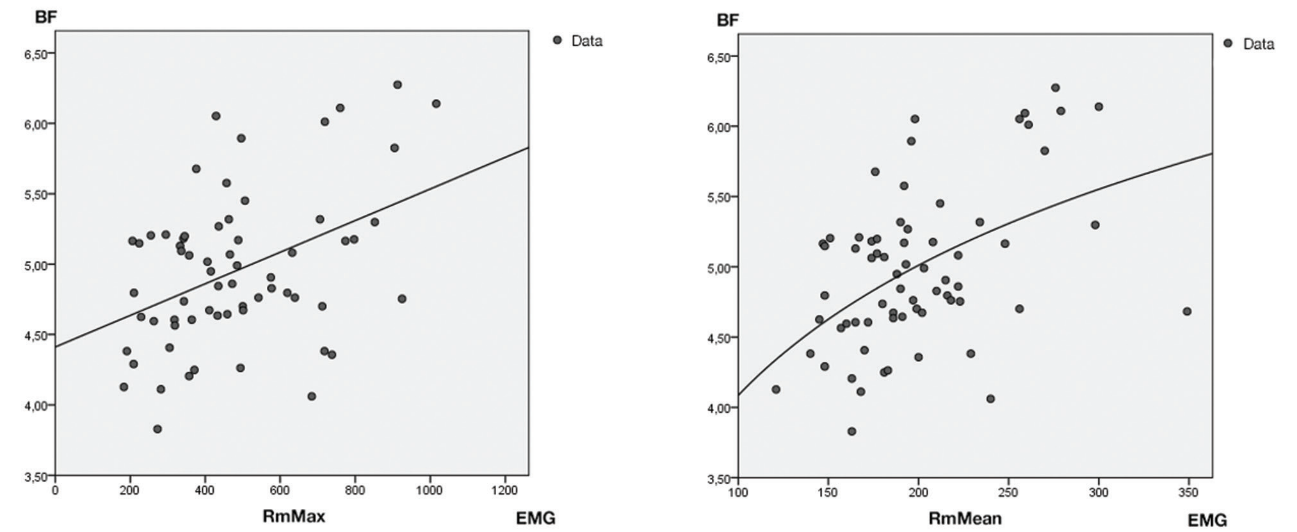

Figure 5. EMG/bite force relationship of the right masseter muscle during 2/3 clenching.

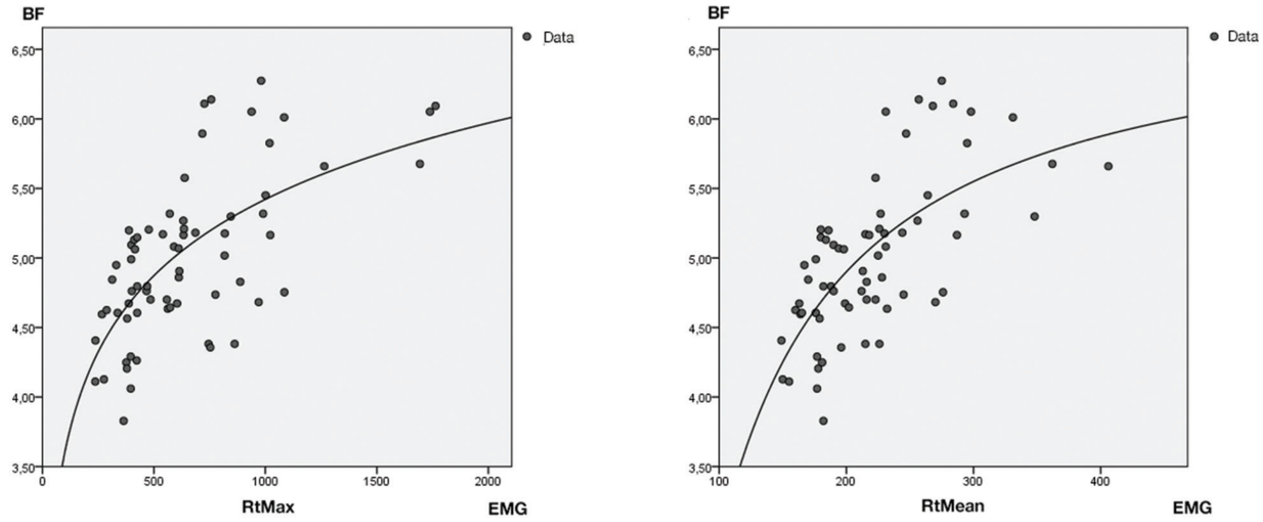

Figure 6. EMG/bite force relationship of the right temporalis muscle during 2/3 clenching.

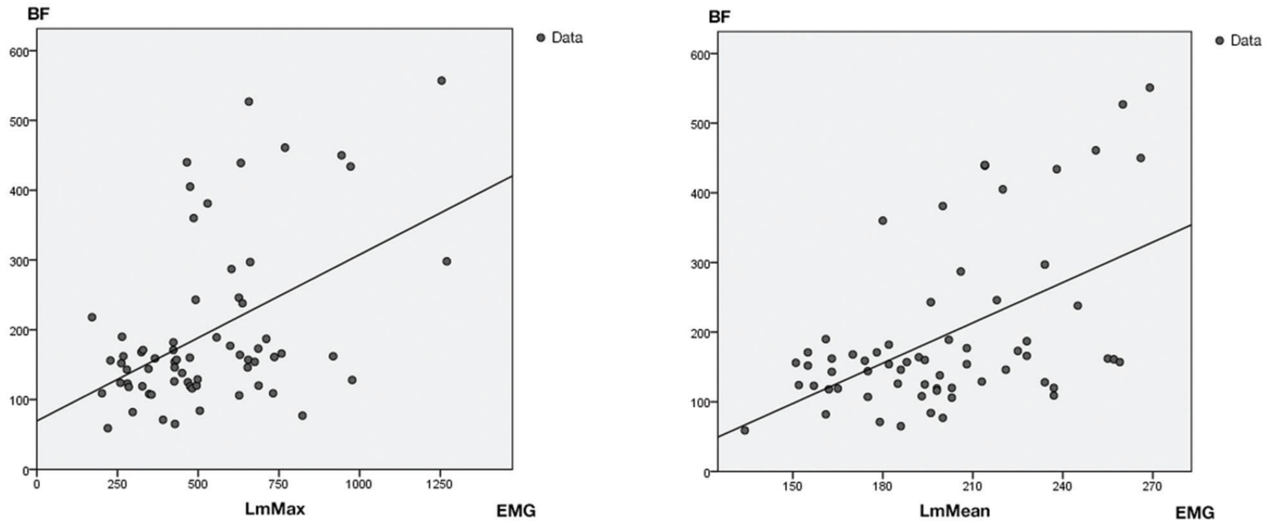

Figure 7. EMG/bite force relationship of the left masseter muscle during 2/3 clenching.

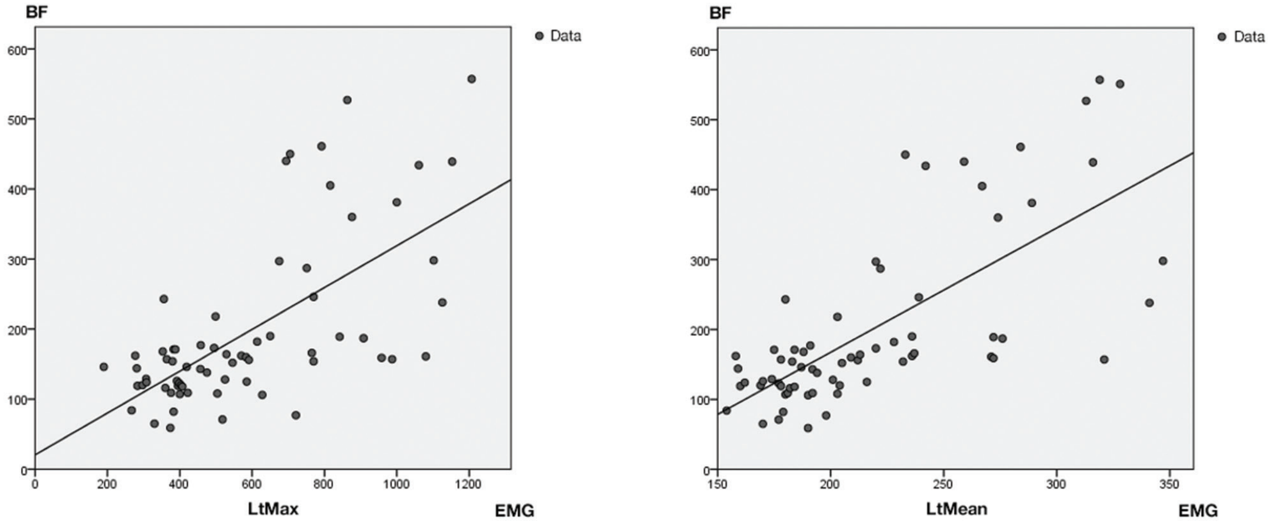

Figure 8. EMG/bite force relationship of the left temporalis muscle during 2/3 clenching.

The regression analysis found a linear model of (p=0.023, R^2=0.078), with parameters Ln(BF)=5,190+0.0004*RmMax for the maximal values of the right masseter and a linear model (p=0.001, R^2=0.148) with parameters Ln(BF)=4,629+0.004*RmMean for the mean values. The correlation is directly proportional and linear **(Fig. 9)**.

For the right temporalis muscle, the logarithmic model was (p<0.001, R^2=0.333) with parameters Ln(BF)=1,002+(0.678*ln(RtMax), for the maximal values and (p<0.001, R^2=0.478) with parameters Ln(BF)=7,035−368,294/RtMean, for the mean values, respectively. The relationship is directly proportional, but not linear. Therefore, when the EMG potentials are above 200 mV, a further increase of the potentials is associated with a lower increase of the biting force **(Fig. 10)**.

On the left side

Regression analysis did not find association between the maximal EMG activity and the bite force values during submaximal clenching of 1/3 of the left masseter muscle.

As to the mean EMG values of the masseter, the linear model of (p=0.002, R^2=0.133) with parameters BF=97,904 + 0.803*LmMean described best the relationship **(Fig. 11)**.

For the left temporalis muscle, this relationship was best described by the model (p<0.001, R^2=0.277) and parameters BF=471,755−120072,661/LtMax for the maximal values and by (p<0.001, R^2=0.311) and BF=649,443−85463,756/LtMean for the mean values **(Fig. 12)**.

DISCUSSION

In the present study, we assessed the type of association between bite force and EMG activity of the temporalis and masseter muscles during maximal and submaximal clenching to determine the most reliable results when occlusal forces of varying magnitude are applied. Therefore, different occlusal forces could be recommended and applied in patients with disorders of the masticatory system (TMD, bruxism, crossbites, etc.), when maximal clenching is risky and not desirable.

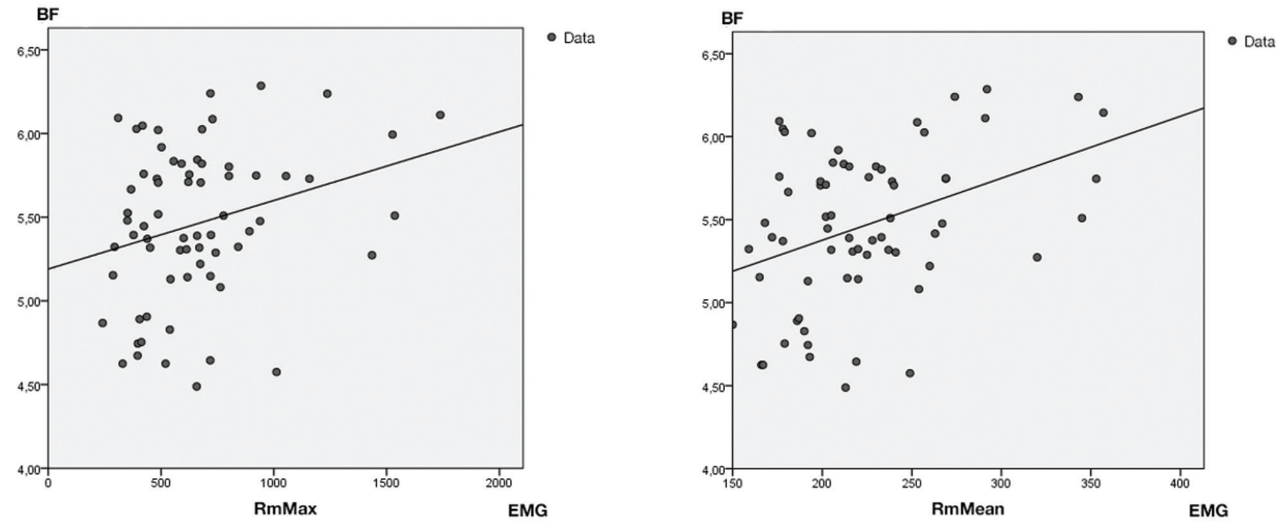

Figure 9. Type of relationship between BF and EMG of the right masseter muscle during submaximal clenching (1/3 max).

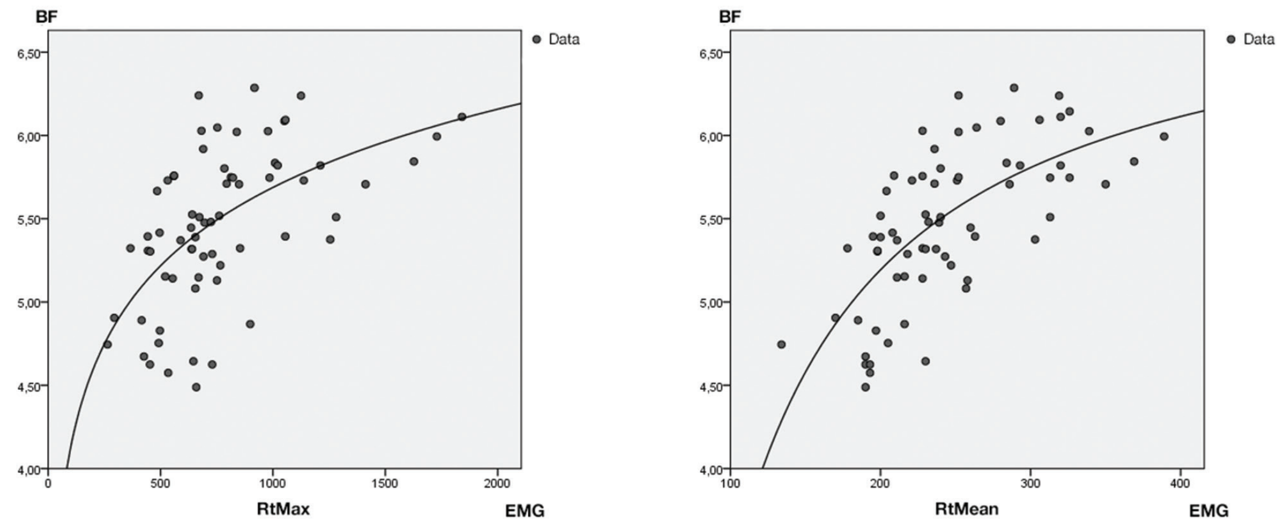

Figure 10. Type of relationship between BF and EMG of the right temporalis muscle during submaximal clenching of 1/3 max.

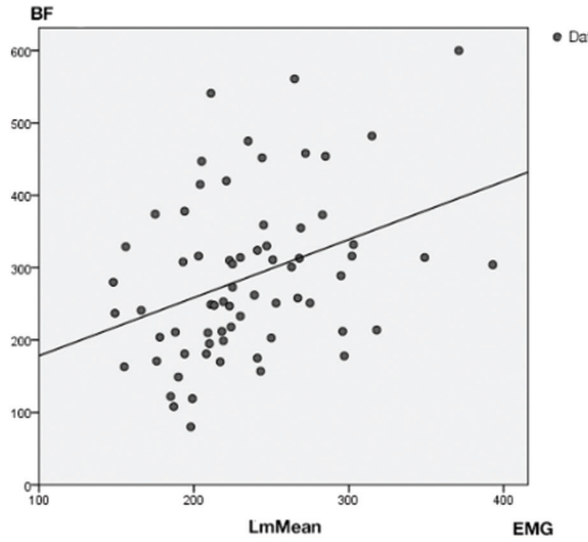

Figure 11. EMG / Bite force relationship of the left masseter during 1/3 clenching.

Some EMG studies suggest that muscles at rest do not display electrical activity, and accordingly, there are no motor units' contractions, while other authors found minimal electrical activity in muscles at rest, associated with the masticatory process.[11] The data concerning the EMG activity of the temporalis and masseter muscles are contradictory. Some authors found that in individuals with complete dentition during maximal clenching, maximal EMG activity is observed in the masseter muscle[12], while other data point to greater activity of the temporalis muscle. Cecílio et al. showed that greater myoelectrical activity was observed in the temporalis muscle compared to masseter in all studied age groups during maximal clenching. The temporalis muscles at rest were found to be more active than the masseter muscles as well. Ferrario et al.[13], in a group of dental students aged 20-27 years, found greater muscular activity in the masseter muscle in males and in the temporalis anterior in females during clenching. Wieczorek et al.[14] found that a higher voltage (131.12 μV) was recorded in the right temporalis of the female compared to 119.63 μV in the male group. The EMG activity showed higher values of the temporalis muscle than the masseter on both left and right side during maximal and submaximal clenching. Although the occlusal contact distribution in both genders was greater on the left side, a predominance of the right side muscles (masseter and temporalis anterior) was present. The authors found that the difference between the right and the left masseter muscles at maximal clench was nonsignificant, and the only significant differences were between the right and the left temporalis muscles.[14] Our data show that during maximal clenching the EMG values of the temporalis muscle were higher but not significant compared with the masseter both on the left and the right side. In this respect, our data are consistent with the findings of Cecílio et al.[3]

In many studies, the temporalis and masseter muscles are used due to their easy access for localization and measurement and because they exhibit the most definite contraction during maximal occlusion.[1,15] Yen et al. investigated the correlation between surface EMG and the bite force of young healthy adults and found a positive correlation between EMG activity and bite force. They did not find any significant differences between the bilateral electromyographic activities of the temporalis and the masseter muscles and bilateral bite force. Some authors measure incisal bite force, as it favors the activity of both temporalis and masseter muscles, which are two essential masticatory muscles (jaw elevators). Moreover, the bite force exerted at the incisors is less influenced by pain and can be used for protocols with many repetitions.[10] However, the first molar area exhibits the largest bite force, and this bite force is similar to the BF at centric occlusion.[15] For this reason, in this study, we also positioned the sensor of the gnathodynamometer in the area of the first molars. Some studies report a linear relationship between electromyo-

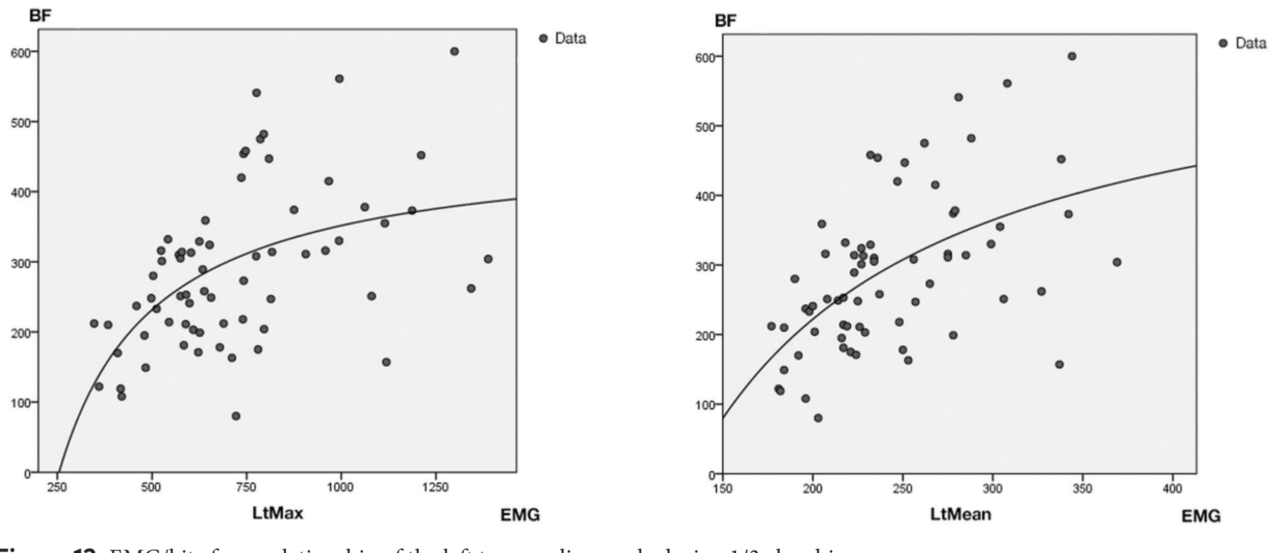

Figure 12. EMG/bite force relationship of the left temporalis muscle during 1/3 clenching.

graphic activity and bite force, but the data on the reliability of this relationship are limited.[5] Gonzales et al. found that the slope of the EMG activity versus bite force for a given biting situation was reliable for both the temporalis and the masseter muscles. Similarly, Yen et al.[1] reported a positive correlation between bite force and sEMG activity of both chewing muscles. The authors note that although some people may use one side more often than the other, no statistically significant difference between the left and the right temporalis and masseter muscle activity and the bite force was observed in a normal population.[1] In this study also, no significant difference was found between the bite force and EMG on the left and the right side. Some data show linear relationship BF/EMG for both temporalis and masseter muscles.[10] In his study Iida et al. also found an almost linear increase of absolute EMG amplitude with molar bite force. In our study, most tests exhibited linear relationship between BF and EMG of the masseter muscle during maximal and submaximal clenching. As to the temporalis muscle, the type of correlation curve was different on the left and the right side when applying different occlusal efforts. On the left, it showed linear relationship during maximal and 2/3 max clenching, while during submaximal clenching 1/3, the curve was not linear. On the right, during maximal and submaximal of 2/3 and 1/3 clenching, the curve was not linear. This allows us to make the conclusion that the correlation between BF and EMG is most reliable either during maximal clenching or submaximal of 2/3 of the maximal BF. If low occlusal forces are applied (1/3 of the maximal BF in this case), the relationship BF/EMG both for the temporalis muscle and for the mean values of the masseter muscle become nonlinear or is lost. Moreira et al. found that the activity of the jaw muscles is linearly related to the average force produced at the incisal region, but as the bite force intensity increased from 5% maximal voluntary clench (MVC) to 20% MVC, no changes in the median frequency of jaw elevator's EMG was observed. Palinkas et al.[16] found approximately 30% higher BF in men than in women and no difference of the BF between left and right. Other researchers also did not find different values of the bite force on the left and right side.[17] In this study, we also found no significant differences in the bite force between left and right, and our findings are in agreement with the data of the aforementioned authors. Different values for the maximum bite force and EMG activity are reported in literature between studies and they are possibly related to differences in the instrumental design, individual tolerance, pain threshold, motivation, and the cooperation of the individuals in the study. [17] As to the type of relationship BF/EMG activity of the masticatory muscles, it is highly dependent on the experimental protocol and the positioning of the sensors for BF measurement, because the latter influences the activation of the masticatory muscles. Pita et al.[18] found greater activity of the masseter muscles compared to the temporalis in both sexes, and did not find statistically significant differences between males and females. Our data show that during clenching, the EMG activity of the temporalis muscle was higher, but not statistically significantly, than that of the masseter. Suvinen et al.[19] reported gradual decrease of the electrical activity of the masseter when the occlusal vertical dimension was increased, while Pita et al.[18] did not find differences in EMG with different occlusal splint thickness. Ferrario et al.[13], during maximal voluntary clench and clench-relax conditions, found similar EMG patterns in male and female subjects. In both maximal voluntary clenching and clench-relax tests, the average potentials were larger in the temporalis anterior muscle than in the masseter muscle.[20] The EMG potentials obtained during the MVC tests were used to determine the best fitting line for estimation of the maximum bite force. A significant linear relationship was found between BF and EMG potentials. The authors consider that this method limited the disadvantages of bite force recording and could be used to obtain indicative values for the occlusal loads to be resisted by prosthetic reconstructions. This finding is in accordance with the observations reported by Pruim et al.[22] for submaximal forces. At higher force levels, the relation deviated from linearity. Similar results are reported by Mao et al.[23] Bakke et al.[24] found a strong linear relationship between unilateral bite forces at both submaximal and maximal loads and masseter and temporalis muscle activities. The relationship is better between EMG and unilateral measurement of BF than between EMG and bilateral measurements. The authors concluded that during isometric contraction relative strength of the electromyographic activity fairly accurately imaged the output of mechanical activity. Bakke et al.[24] ranged the submaximal bite force between 12.5% and 87.5% of maximal unilateral bite force, while Ferrario et al.[20] used approximate values of 14-28-42-55% of estimated maximal bilateral force. As these authors found significant linear correlation of BF/EMG, they concluded that the EMG values during maximal clenching could be used to calculate the maximal BF. In this study, we measured the EMG activity during maximal clenching and submaximal, approximately 2/3 and 1/3 of the maximal BF. Our results show that during decrease of the occlusal load to 1/3 of the maximal bite force, the linearity of the association BF/EMG is decreased or lost.

CONCLUSIONS

The temporalis and masseter muscles show different BF/EMG relationship curves, and respond differently to different occlusal force. The temporalis muscle' curves on the left and the right side are not identical. Linear relationship is more typical for the masseter muscle, compared to temporalis, and it could be considered more appropriate for indirect evaluation of BF using EMG when there is a risk of direct measurement of bite force. Concerning the occlusal load, maximal and submaximal 2/3 clenching can be recommended as more reliable, as at low occlusal load (1/3) the linearity is decreased or lost.

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Тип корреляции между силой укуса и ЭМГ–активностью височных и жевательных мышц при максимальном и субмаксимальном сжимании

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Резюме

Введение: Максимальная сила прикуса является важным фактором, определяющим жевательную функцию и имеет важное значение для оценки состояния зубов. Силу укуса обычно измеряют с помощью гнатодинамометрии.

Цель: Целью исследования было изучить тип корреляции между электромиографической активностью жевательных мышц и силой укуса при одновременном измерении и оценить использование ЭМГ-активности как варианта косвенного определения силы укуса.

Материалы и методы: В исследование включены 68 человек, средний возраст 18.4±6.1 года: 33 мужчины и 35 женщин. Силу укуса и sЭМГ измеряли у всех 68 испытуемых последовательно с правой и левой стороны во время максимального (1) и субмаксимального (2/3 и 1/3) сжатия. Статистический анализ проводился с помощью IBM SPSSStatistics, версия 23.0.

Результаты: ЭМГ-активность и значения максимальной силы укуса не показали существенных различий с левой и правой стороны. Для ассоциативной силы укуса обнаружена линейная зависимость: ЭМГ-активность жевательной мышцы при максимальном и субмаксимальном (2/3) сжимании, тогда как при силе сжимания 1/3 ассоциация утрачивалась. Для височной мышцы эта зависимость была линейной для левой стороны при максимальном и субмаксимальном сжатии на 2/3 и нелинейной для правой стороны. При сжатии на 1/3 линейность терялась как с левой, так и с правой стороны.

Заключение: Жевательная мышца демонстрирует стабильную линейную связь между СУ и ЭМГ с обеих сторон и может считаться надёжной для косвенной оценки силы укуса путём измерения потенциалов ЭМГ. При низких окклюзионных силах (1/3) линейность жевательных и височных мышц снижается или теряется.

Ключевые слова

сила укуса, жевательные мышцы, поверхностная электромиография, тип корреляции