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Lack of agreement between objective and subjective measures in the evaluation of masticatory function: A preliminary study

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ABSTRACT

The evaluation of mastication is important to understand the masticatory behavior and diagnose feeding difficulties. The objective of this preliminary study was to verify if there is agreement between objective and subjective validated methods of chewing evaluation in a convenience sample which consisted of 32 adolescents (mean 15.5 years), complete permanent dentition and free of tooth decay. The Quality of Masticatory Function Questionnaire with the Food-Mastication, Habits, Meat, Fruit and Vegetables domains was used in the subjective evaluation. The objective aspects consisted of maximum bite force (BF) and masticatory performance (MP) by mastication of cubes of test-material and sieving to determine the median particle size (X_{50}) and distribution in the sieves ("*b*"), and by the colorimetric method using colorchangeable chewing gum. Data were submitted to exploratory analysis, normality test and correlation tests (Pearson/Spearman). The correlation between BF and X_{50} ($r = -0.43$; $p = 0.02$) and between BF and MP chewing gum ($r = 0.53$; $p = 0.002$) was significant with large effect size. The MP evaluated by chewing gum correlated with X_{50} ($r = -0.34$; $p = 0.055$), but not with "*b*" ($r = -0.06$; $p = 0.73$), while "*b*" correlated only with X_{50} ($r = 0.52$, $p = 0.002$). No significant correlation was observed between the objective measures and the total score of the subjective evaluation; only a negative correlation was observed between "b" and Meat domain ($r = -0.40$; $p = 0.023$). The objective methods showed moderate correlation with each other and no agreement between the objective and subjective methods was observed in this sample of healthy adolescents, emphasizing the importance of both aspects in the evaluation of masticatory function.

1. Introduction

Chewing is the first step in the process of digestion; it is defined as a sensory-motor activity, which process is complex and involves activities of the facial, elevator and suprahyoidal muscles and the tongue [39]. The basic rhythmic activity of the jaw-opening and closing muscles is evoked by a central pattern generator located in the brain stem, being stimulated by the activity of higher centers or by intra-oral afferences [35,36]. The main purpose of mastication is to break down foods into smaller particles that bind to each other through the saliva, forming a food bolus read for swallowing and digestion.

During chewing, food taste and texture are perceived and modulate the process; for ex., food hardness influences the masticatory force, activity and the amplitude of mandibular movements [15–17]; in addition, the number of chewing cycles also depends on food characteristics, such as fat and water content [12,22]. The teeth are extremely important for mastication, especially because the posterior teeth form the occlusal area where the food is grounded. Teeth loss, the presence of cavities or inadequate restorations, malocclusion or periodontal disease can impair masticatory function [9,23–25]. Salivary flow rate, on the other hand, is weakly correlated with the number of chewing strokes needed to prepare the food for swallowing, although adding fluids affects both the physiology (muscle activity and number of cycles) and the sensory perception, especially for dry foods [22,41]. A poor mastication may lead to changes in food selection, thus negatively affecting the orofacial muscle tonus or even the nutritional status [20].

Because of its complexity, the evaluation of the quality of masticatory function may comprise many techniques that cover all aspects of chewing and, in general, are classified as objective and subjective

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methods. The subjective methods include those instruments intended to gather the patients' or study participants' ratings of their chewing experience and satisfaction [6] whereas objective measures generally involve bite force, electromyography and ultrasonography of masticatory muscles, masticatory performance determination, among others [41].

Masticatory performance and efficiency are two different objective methods intended to examine the capacity to reduce the size of food particles by chewing for a standardized period, and the number of chews necessary to render food ready for swallowing, respectively [32,41]. A variety of natural (carrots, peanuts, almonds and Brazil nuts) and artificial test-materials (Optosil^R and Optocal Plus^R) may be used to determine masticatory performance, measuring the particle size distributions of the food bolus. Artificial test-materials are considered preferable to natural foods since their physical properties are more reproducible and do not undergo seasonal variation in texture [8], although it remains unclear whether chewing such materials in fact simulates natural chewing [44]. In that sense, other methods have been developed and proposed for evaluating the ability of mixing food, such as chewing gum and paraffin wax [27], which have advantages such as taste (gum), stability [29], and not being time consuming.

Bite force and occlusal contact area have also been studied as objective parameters of mastication [34] and reported as key determinants of masticatory performance [11]. Bite force depends on jaw muscles volume, activity, and coordination [38]. Measurement of the maximum bite force is an attempt to quantify the total force which can be developed by the jaw-closing muscles [7].

Very few studies are found in the literature which tried to examine the correlation between masticatory performance or efficiency and the subjects' opinion about his/her own mastication. This fact is probably due to the few number of validated instruments to measure the subjective aspects of mastication [6] and the assumed little awareness of one's own chewing characteristics [43]. Slagter et al. [31] and van der Bilt et al. [37] reported only a weak correlation between masticatory ability (perceived ability) and masticatory performance in patients submitted to prosthetic treatment. Thus, the relationship between objective and subjective measures of mastication is still controversial for dentate subjects and there is a lack of studies which have employed validated methods in such evaluation.

The hypothesis to be tested was that the evaluation of subjects' ratings of their chewing ability and satisfaction agree with objective measures of masticatory quality. Thus, the aim of this study was to evaluate and test the correlation between the scores of masticatory quality gathered from a validated instrument, maximum bite force and masticatory performance examined by sieving and colorimetric methods in a convenience sample of healthy adolescents.

2. Methods

2.1. Ethical and reporting considerations

This study was approved by the Research and Ethics Committee of Piracicaba Dental School, University of Campinas (protocol n. 152/2014). The procedures and possible discomforts/risks were fully explained to the adolescent and their parents/guardians, who gave voluntary signed consent to participate in this research. The reporting of this research follows the STROBE recommendations for reports of observational studies.

2.2. Sample

We selected a convenience sample of 32 healthy adolescents (13 females and 19 males, aged 14–17 years) in two public schools of Piracicaba (SP, Brazil). Sample size was calculated according to results found by Sugiura et al. [33], who compared the mixing ability and masticatory performance tests using different test-materials. Considering a correlation coefficient of $r = -0.56$ between methods, 80% power and an alpha level of 0.05, we determined that 24 subjects would be needed. To prevent losses and missing data, we opted to include a larger sample.

Researchers conducted an interview with the adolescent to verify the medical and dental history. The inclusion criterion was the presence of permanent dentition (exception of third molars). The exclusion criteria considered factors that could compromise the masticatory evaluation, such as: presence of caries and/or tooth loss; periodontal disease (pockets > 3 mm); severe malocclusions (Angle's Molar relationship of Class II or III); pain of dental origin; history/current orthodontic treatment; symptoms of temporomandibular disorders in the last 30 days; chronic diseases such as asthma/bronchitis, epilepsy, cancer, rheumatoid arthritis, diabetes *mellitus* or hypertension; chronic use of drugs such as benzodiazepines, anti-inflammatory agents, steroids and antidepressants; dietary restrictions; dry mouth or salivary glands diseases; and inappropriate behavior and/or refusal to cooperate.

The oral examination was performed using a clinical mirror with LED light and exploratory probe after oral hygiene instructions. Caries experience was determined by the number of decayed, missing, and filled permanent teeth (DMFT) and data on probing depth were obtained in accordance to the Community Periodontal Index [42].

2.3. Evaluation of bite force

Maximum unilateral bite force was obtained using a digital gnatodynamometer (model DDK, Kratos Equipamentos Ind. Ltda., Cotia-SP, Brazil. For more details, please visit: http://www.kratos.com.br/equipamentos-especiais.htm). The device has a fork force with the following dimensions: 12 mm high, 15 mm depth and 15 mm width, which provides an accurate measure of the force generated by each pair of teeth, as described in the study of Rosar et al. [26].

During the assessment, the participant remained seated, with the head in a relaxed position and the fork was placed between the maxillary and mandibular arches, over the permanent first molars. The adolescent was instructed and trained before biting with maximum force, and two measurements were made for each side of the dental arches (left and right), with an interval of 1 min. The maximum value gathered was considered as the maximum bite force (N).

2.4. Evaluation of masticatory performance

Masticatory performance was assessed using two methods: by the determination of the individual capacity of fragmentation of a test-material (Optocal) [18] and by a colorimetric method (color-changeable chewing gum) [21].

First, the adolescents chewed on 17 cubes of Optocal for 20 mastication cycles, monitored by the examiner. The fragmented particles were then expelled and after washing and drying, the particles passed through a series of 10 granulometric sieves with meshes ranging from 5.60 to 0.71 mm, connected in decreasing order. The set was maintained under vibration for 20 min. The particles retained on each sieve were removed and weighed on an analytical scale (precision of 0.001 g). The weight distribution of the particles was described by a cumulative function (Rosim–Ramler equation). The degree of fragmentation of the material is then given by the median particle size (X_{50}), which is the aperture of a theoretical sieve through which 50% of the weight of the fragmented material could pass [37]: $Qw(X) = 1\text{-}2\text{-}(X/X_{50})^b$ [18]. The variable "*b*" (broadness variable) represents the distribution of particles in the different sieves. As the experiment was performed twice, the portion that showed a lower loss percentage between initial and final weight was considered.

In the next day, the colorimetric method was performed with the subjects being asked to chew the color-changeable gum for 1 min, as they usually chew ("Please chew the gum well"). The time spent was measured using a chronometer. The chewed gum was extracted

Fig. 1. Chewed gum and color scale specifically designed for the evaluation of color changes from yellowish-green to red [28]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

immediately after 1 min and compressed between two plastic films (Fig. 1) for color measurement using a visual color scale [10]. The test was repeated twice for the same subject.

The gum base contains red, yellow, and blue dyes, citric acid and xylitol. The red dye is pH-sensitive and appears under neutral or alkaline conditions. As the pH inside the chewing gum is kept low by the citric acid, the color of the chewing gum remains yellowish-green before chewing. With the progression of chewing, the color of the chewing gum turns from yellowish-green to red because the yellow and blue dyes seep into saliva, and the red dye appears because of elution of the citric acid [44].

2.5. Subjective evaluation of masticatory quality

We used a self-applied questionnaire (Quality of Masticatory Function Questionnaire) which consists of 26 questions specifically related to the frequency and difficulty of chewing different types of foods in the last two weeks. This Canadian questionnaire was translated to Portuguese, adapted and validated previously [13,14].

The questions are distributed in five domains: Food-Mastication, Habits, Meat, Fruit and Vegetables, which have 5 *Likert*-response options ranging from "always" to "never" or "a lot" to "no difficulty" and explore the difficulty with mastication in daily life considering that higher the score, worse the quality of mastication. The following are examples of these questions:

- Do you have difficulty chewing hard, raw fruits, without cutting them (e.g.: apples)?
- Do you have to drink while eating to facilitate swallowing?
- In general, is the food well chewed before being swallowed?

2.6. Statistical analysis

Statistical analyses were performed using BioEstat 5.3 (Mamirauá, Belém, PA, Brazil) and SigmaPlot 13 (Systat Software Inc., San Jose, CA, USA). An alpha level of 5% was considered. Shapiro-Wilk test showed that the distributions of the X_{50} deviated from normality. The exploratory analysis consisted of means, standard deviation, medians and quartiles. There were no missing data.

When interpreting the answers of the questionnaire, it was observed that NA (not applicable) was checked by nine volunteers, and the missing values were changed by the median of the items' score for that domain, as previously described [13].

Because of their skewed distributions, X_{50} data were transformed to more closely approximate normality using square root transformation. The total score gathered from the scale also deviated from normality (Fig. 2) and was squared transformed.

A correlation matrix was obtained for objective and subjective measures of mastication, using Pearson's (between objective measures) and Spearman's (between subjective measures) correlation tests for parametric and non-parametric data, respectively.

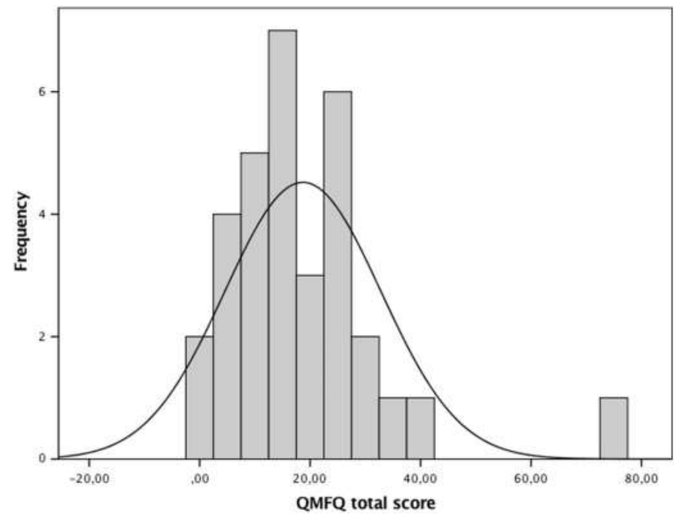

Fig. 2. Distributions of the Quality of Masticatory Function Questionnaire (QMQF) total score among participants.

The Cohen's *d* effect size for each correlation coefficient was calculated using the formula [4]: $d = 2r / \sqrt{1 - r^2}$.

3. Results

The exploratory analysis in accordance to demographic and clinical data is shown in Table 1. Dispersion measures of the objective (bite force, masticatory performance) and subjective measures (scores gathered from each domain of the questionnaire) are also shown.

Table 2 shows the correlation coefficients between the objective and subjective evaluations of the masticatory function. The correlation between bite force and masticatory performance evaluated by means of Optocal X_{50} and chewing gum was significant, with a large effect size. The masticatory performance as evaluated by chewing gum showed a negative correlation with X_{50} ($r = -0.342$), with a p-value of 0.055 and an effect size equal to 0.75 (56% of variance explained, that is, large), which means that if the sample was slightly larger it would reach an alpha level lower than 5%. The parameter "*b*", which represents the distribution of particles in the different sieves, did not correlate significantly with masticatory performance evaluated by chewing gum, but did significantly with X_{50}.

No significant correlation was observed between total score gathered from the questionnaire and bite force and masticatory performance (objective measures) (Figs. 3 and 4). Only a weak negative correlation was observed between "*b*" and the domain "Meat" of the questionnaire.

4. Discussion

To our knowledge, this is the first study which employed validated methods to test the correlation between objective and subjective measures of mastication. Although preliminary, interesting findings showed that objective measures (both masticatory performance methods applied and bite force) correlated significantly between each other with large effect size. However, concordance between objective and subjective measures were absent.

The maximum bite force is not usually applied during habitual chewing and because of the large number of devices and methodologies found in the literature, it has been criticized for not being easy to standardize and compare. An intraoral device was also proposed, allowing natural mastication without an increase in the vertical dimension [30], thus reducing the risk of muscle hyperextension (which would decrease the muscle power). Nevertheless, bite force is considered a good parameter of the masticatory status and its performance

Table 1
Exploratory analysis in accordance to demographic and clinical data (n = 32).

	Age (y)	Sex	BMI (Kg/m^2)	DMFT	Bite force (N)	MP chewing gum	MP X_{50}	MP *b*	Food-mastication scores	Habits scores	Meat scores	Fruit scores	Vegetables scores
Frequency	–	13♀ 19♂	–	–	–	–	–	–	–	–	–	–	–
Mean	15.43	–	22.81	1.22	491.09	7.59	3.37	2.10	4.38	4.47	3.78	2.88	3.19
SD	1.08	–	5.53	1.91	204.23	1.19	0.93	0.39	5.52	3.37	4.48	3.32	2.44
Median	15.20	–	20.96	0.00	492.31	7.75	3.31	2.12	3.00	4.00	3.00	2.50	4.00
25%	14.68	–	18.18	0.00	326.08	7.00	2.72	1.90	0.75	1.75	0.00	0.00	2.00
75%	15.95	–	26.90	2.00	605.80	8.25	3.65	2.32	6.00	6.00	5.00	4.00	4.00

BMI, body mass index; DMFT, number of decayed, lost and filled permanent teeth; MP, masticatory performance; X_{50}, median particle size; MP *b*, distribution of the particles; SD, standard deviation.

[19], as confirmed by the present results. Indeed, the bite force may represent over 60% of the variance in masticatory performance [41].

In this study, bite force showed moderate correlation with both methods of masticatory performance evaluation (chewing gum and X_{50}), although it did not correlate with the broadness of distribution of the Optocal particles ("*b*"). The absence of correlation with "*b*" might be because as better as someone chew optocal particles (stronger is the jaw musculature), as more fragments will go down to the bottom plate, reducing distribution along sieves. Again, when comparing with the chewing gum, the better someone chew the gum, the color goes straight to a solid red color which was not correlated with the distribution of particles in the sieves. When median particle sizes of dentate subjects reach a lower limit of about 1 mm they can no longer decrease upon further chewing and it turns difficult to differentiate between subjects [7,40].

The two types of masticatory performance evaluation showed agreement, that is, higher the degree of gum red color, lower the Optocal's median particle size. Optocal is a test-material which is not usual in flavor, taste and texture whereas chewing gum has the advantage of being routinely consumed, with good flavor and stability producing fast reliable results [10]. A previous study compared masticatory performance obtained with the comminution of both Optosil and Optocal materials and the results found by mixing of a two-colored chewing gum [40]. Contrary to our results, that study found no significant correlation between comminution tests and chewing gum in young subjects. The authors supposed that young volunteers could easily mix the two colors of chewing gum, making it difficult to discriminate different conditions; thus, the quantification of the color degree of mixing a gum may be a good method to examine the masticatory function in subjects with a limited masticatory performance, while test-materials could be better indicated to our type of sample composed by teenagers with good oral health or dentate adults. As the physical properties of foods we usually ingest daily change as mastication progresses, the chewing gum may have limitations since it is not broken up [43]. Besides, as the test-materials' hardness, fat content, size, and structure may influence the evaluation [2], it is advisable to use several methods when assessing masticatory performance.

According to our results, there was no correlation between the objective measures and the scores gathered on a self-administered questionnaire, corroborating previous findings in edentulous subjects [5]. Indeed, these results reinforce the conception that the subjective evaluation of masticatory performance includes other aspects such as adaptation, eating habits, cultural and regional aspects and preferences that cannot be obtained from direct measures as reported previously [1,41]. While the objective measures provide specific values of masticatory function, the questionnaire involves information related to chewing behavior and difficulties while chewing [13,14]. In addition, our previous study [14] showed that a complete and structured instrument intended to evaluate the subjects' perceptions of their chewing ability is preferable than a simplified one (with yes/no answers), which make it possible to assess if the subject avoids certain kind of food (meat, fruit, vegetable) because of its size or consistency [14].

Previous findings gathered from simpler methods showed that self-assessed chewing ability and masticatory performance do not tend to correlate [37,41], especially because people may judge their ability better than it really is [3,41]. A significant negative correlation was observed between the variable "*b*" and "Meat" domain, meaning that subjects with little difficult during chewing meat may show a small distribution of Optocal particles in the different sieves, as most of fragments were found at the bottom plate.

Table 2
Correlation matrix between objective and subjective measures of mastication.

		MP chewing gum	MP X_{50}	MP *b*	Food-mastication domain	QMFQ habits domain	QMFQ meat domain	QMFQ fruit domain	QMFQ vegetables domain	QMFQ total scale
Bite force	r	**0.526**	**− 0.425**	0.154	− 0.038	− 0.004	− 0.029	− 0.165	0.027	− 0.213
	p-value	0.002	0.015	0.400	0.834	0.980	0.872	0.364	0.881	0.243
	Effect size *d*	1.26	0.95	0.30	0.05	0.00	0.05	0.35	0.05	0.45
MP chewing gum	r	–	**− 0.342**	− 0.064	− 0.278	0.018	− 0.029	− 0.096	− 0.044	− 0.260
	p-value		0.055	0.728	0.123	0.919	0.872	0.598	0.809	0.151
	Effect size *d*		0.75	0.10	0.60	0.05	0.05	0.35	0.10	0.55
MP X_{50}	r	–	–	**0.523**	− 0.165	− 0.116	− 0.150	0.410	− 0.205	− 0.066
	p-value			0.002	0.365	0.522	0.410	0.516	0.258	0.718
	Effect size *d*			1.25	0.35	0.25	0.35	0.90	0.45	0.10
MP *b*	r	–	–	–	− 0.137	− 0.160	**− 0.401**	− 0.335	− 0.317	− 0.302
	p-value				0.451	0.378	0.023	0.061	0.077	0.093
	Effect size *d*				0.25	0.35	0.85	0.70	0.65	0.65

MP, masticatory performance; X_{50}, median particle size; *b*, distribution of the particles; QMQF, Quality of Masticatory Function Questionnaire; d, Cohen's effect size.
Correlation coefficients in bold means statistically significance ($p < 0.05$).

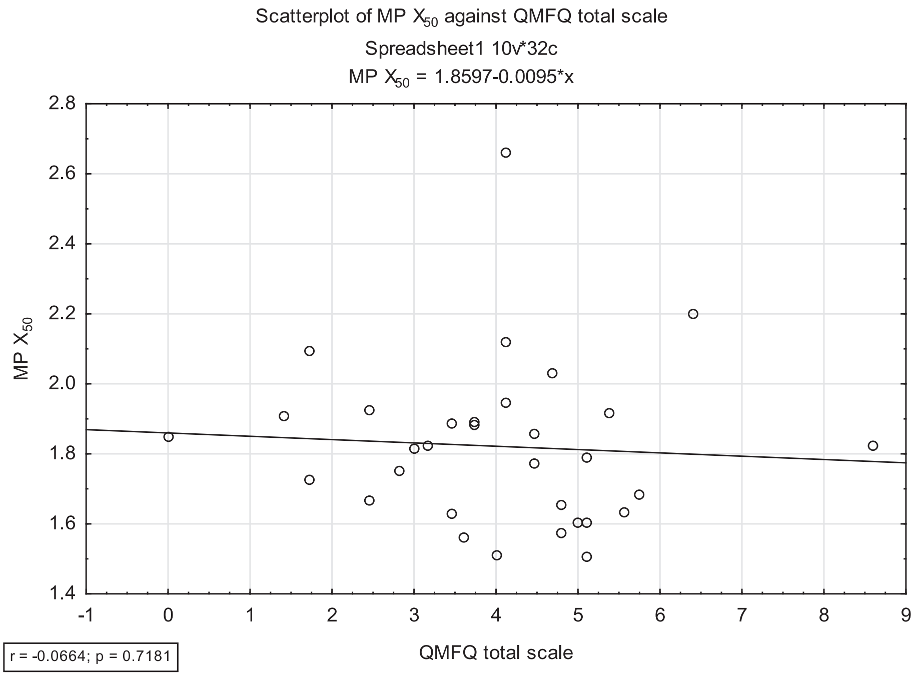

Fig. 3. Correlation between Quality of Masticatory Function Questionnaire total score and Optocal median particle size (X_{50}).

Taken together, the results suggest that there is no better method in the evaluation of masticatory function, but rather one evaluation complements the other. Chewing involves both physical and psychosocial aspects and, because of their complexity, all methods seem to be of importance in understanding the individuals' chewing function and behavior in her/his daily life, beyond its importance in the clinical point of view. Although interesting and new, this preliminary study found results that should be confirmed in a further study which includes patients undergoing oral rehabilitation to guarantee their external validity.

5. Conclusions

In this preliminary study, objective methods showed a moderate correlation with each other, while no agreement between the objective and subjective methods was observed, emphasizing the importance of both aspects in the evaluation of masticatory function, in understanding the individuals' chewing behavior and during the treatment planning.

Declaration of conflict interests

The authors declare no conflict of interests.

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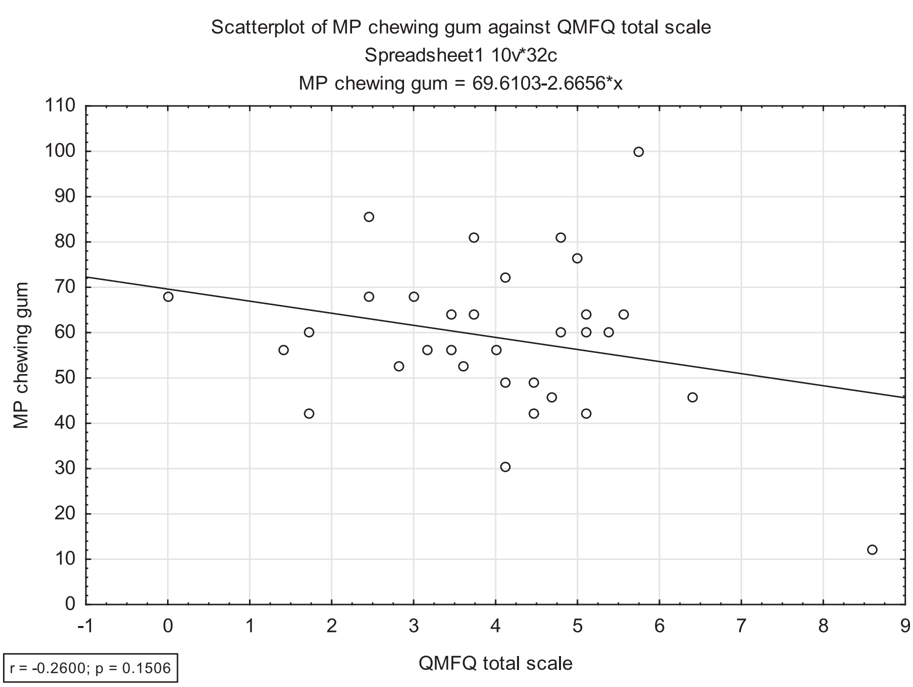

Fig. 4. Correlation between Quality of Masticatory Function Questionnaire total score and masticatory performance evaluated by chewing gum.

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