Methods for Evaluation of Masticatory Efficiency in Conventional Complete Denture Wearers: A Systematized Review

Oliveira NM[1], Shaddox LM[2], Toda C[3], Paleari AG[1], Pero AC[1], Compagnoni MA[1]

[1]Department of Dental Materials and Prosthodontics, Araraquara Dental School, Sao Paulo State University (UNESP), Araraquara, São Paulo, Brazil. [2]Departament of Periodontology, College of Dentistry, University of Florida, Gainesville, Florida, USA. [3]Department of Prosthodontics, University of Federal do Amazonas, UFAM, Manaus, Amazonas, Brazil.

Abstract

The objective of this study was to present a systematized review of different methods used to evaluate the masticatory efficiency in conventional complete denture wearers. A survey was conducted in the databases PubMed, Scopus, and Cochrane, seeking scientific articles according to the previously selected terms: "Masticatory performance", "Masticatory efficiency" and "Chewing ability complete denture". Moreover, complementary studies have been carried out with library manual search/databases, which included studies related to different ways to assess masticatory efficiency, specifically as it related to conventional complete denture wearers. Forty three papers were selected to be used in the present review. Despite the wide variety of methodologies in the literature, the sieves method is currently considered the gold standard method to evaluation of conventional complete denture wearers masticatory efficiency, since it is the simplest, does not depend on specific devices (beyond the set of sieves), allows for a rational assessment, and it has been widely reproduced in various types of oral rehabilitation. More, the almond, as natural test food, and the optocal (made from the molding material Optosil), as artificial test food, are the most constantly employed test foods to evaluate masticatory efficiency.

Introduction

The loss of natural teeth not only results in aesthetic issues to individuals, but can also seriously risk masticatory function. Long-term edentation could eventually result in bone resorption, temporomandibular disorders or muscle hypotonicity which ultimately leads to direct damage to the masticatory process [1]. Furthermore, a reduction in the physiological secretion of gastric acid is characteristic of the aging human process which reinforces the importance of efficient mastication to start food digestion processes [2]. The process of chewing, which typically ranges from 10 to 40 masticatory cycles allows food to be effectively reduced in size and moistened by saliva, thus forming a bolus, which can be easily swallowed [1,3,4].

Although there are limitations, conventional complete dentures still represent the most common therapy for edentulous individuals [5]. However, problems such as discomfort and difficulty in chewing certain foods are generally reported by its wearers [4,5] as a result of a reduced masticatory efficiency, which ranges from 16% to 50%, when compared to dentate subjects [2,6]. Seeing that in normal individuals oral food preparation and bolus sizing are adapted to swallowing capacity [7,8], this poor masticatory efficiency of complete denture wearers oftentimes is compensated by chewing longer and swallowing coarser food particles [4,8].

In complete dentures wearers, both the subjective experience and the objective masticatory efficiency with their dentures are determined by several factors such as age, sex, duration of edentulism, oral conditions and previous dentures experiences [9,10]. Their chewing, admittedly limited, may predispose these individuals to a variety of problems, such as inability to chew tough or hard foods, oral pain or instability of their complete dentures [10].

Given the importance of evaluating chewing effectiveness, mainly related to complete denture rehabilitation, a wide variety of methods employed in the analysis of masticatory efficiency have been studied [7,11]. Despite the acceptance of some of these methods, there is still a search for more simplified and effective ways of obtaining such an index. Oftentimes, it is difficult to choose only one method that prevails among others. Thus, the aim of this paper is to present a review of the different methods used for the evaluation of masticatory efficiency in conventional complete denture wearers.

Materials and Methods

A survey was conducted in the databases PubMed, Scopus and Cochrane, seeking scientific articles according to the previously selected terms: "Masticatory performance", "Masticatory efficiency" and "Chewing ability complete denture". Moreover, complementary studies have been carried out with library manual search/databases. In this systematized review were included studies related to different ways to assess masticatory efficiency, specifically as it related to conventional complete denture wearers. The search focused in articles published up to November 2013. The last survey was conducted on 11-15-2013.

Results

Svpapers were selected to be used in the present review. The theme "Methods for evaluation of masticatory efficiency in conventional complete denture wearers" is presented in the sub-sections that follow.

Terminology

The current terminology used in research related to masticatory capacity/ability is rather confusing in the studies existing in literature, and not always there is a correct differentiation of

Corresponding author: Dr Marco Antonio Compagnoni, Department of Dental Materials and Prosthodontics, Araraquara Dental School, Sao Paulo State University (UNESP), Rua Humaitá 1680, 14801-903 Araraquara, SP, Brazil. Tel: +55-16-33016411, Fax: +55-16-33016406, e-mail: compagno@foar.unesp.br

Table 1. *Selection process of scientific articles in different databases.*

Database	Research terms	Total papers	Selected by title	Selected by abstract	Used in review
PubMed	**"**Masticatory performance"	459	22	12	12
	"Masticatory efficiency"	360	11	8	8
	"Chewing ability complete denture"	172	9	5	5
Scopus	**"**Masticatory performance"	595	23	12	12
	"Masticatory efficiency"	427	13	10	8
	"Chewing ability complete denture"	114	4	4	4
Cochrane	**"**Masticatory performance"	56	3	2	2
	"Masticatory efficiency"	49	3	1	1
	"Chewing ability complete denture"	44	2	0	0

terms, although it has been proposed [4,12-15]. The term masticatory performance can be defined as the ability to grind certain portion of food with determined number of masticatory cycles, while the term masticatory efficiency is related to the amount of chewing necessary to achieve a given degree of grinding of test food, independently of the number of masticatory cycles. However, despite an attempt to standardize these terms has been published, there is a lack of authors acceptance to this semantics [14].

Sieves system

There is a great variety of methodologies describing masticatory efficiency. Old methodologies, adaptations or variations of such, methods using specific apparatus, including new descriptions, are found in this field of scientific research. Among these, the use of sieves system is undoubtedly the most indicated method for measuring masticatory efficiency, even in complete dentures wearers [16]. Many variations of the sieves method, first introduced by Gaudenz in 1901, are currently found in the literature related to chewing [17]. The protocols differ in many ways, such as:

(1) The number of chewing cycles performed, or chewing time.

(2) The number of sieves the crushed test food is subjected to.

(3) The orifice diameter of the mesh sieves.

(4) Washing of the contents during the crushed almonds passage through the sieves system or passage of the almonds after they have been already dehydrated.

(5) Number of almonds for chewing, among others factors [1,14,18-24].

However, considering this method, the key point is that the more particles ground by mastication reach the smaller diameter sieves, the better is the individual masticatory efficiency rated [11]. Additionally, there is a variability in natural test foods already used, according to Manly and Bradley and Kapur et al. such as: Peanuts, hazelnuts, carrots, ham, coconut, lettuce, celery, apple, almonds, sardines, beef, sausage, soy, boiled egg, potato, turnips, bread and rice, among others, distributed into different classes food (fish, nuts, fruits, grains, meat and vegetables) [14,19]. In the study by Kapur et al. was proposed an evaluation of various test foods used for measuring masticatory efficiency in denture wearers, and they concluded that the fibrous ones (such as lettuce and celery) were more difficult to be chewed, while chestnuts, sausages and sardines were among the easiest ones [19]. Moreover, it was observed that raw carrot was amongst the most resistant foods, presenting a high degree of accuracy in reliability tests, and thus a good candidate for subsequent studies.

In addition to the natural test foods already mentioned, artificial materials have also been and are currenlty employed for masticatory efficiency analysis. Among these materials, we can highlight the optical [20-22,25,26], made from the molding material Optosil (condensation silicone), modified gelatin and chewing gum [24,27-30]. The use of Optosil as material for evaluation of masticatory efficiency is common nowadays and was supported by Edlund and Lamm, who tested it its properties by electromyographic analysis, deformation rate and storage and strength in contact with water [31]. According to these authors, the advantages of this material were the absence of degradation by water, grinding index easily established after chewing, and easy preparation.

Studies that aim the improvement of already established method of sieves are available in the literature. In an interesting attempt to decrease the concentration of oils in almonds and consequently their agglutination, a simplified methodology for placing almonds in a microwave was proposed by Al-Ali et al. [32]. According to these authors, by placing the whole almonds in the microwave, its oil content was reduced and could therefore reduce particle agglomeration. Thus, this procedure would eliminate the need for washing the particles chewed through the sieves, reducing the test time, which make this method useful for several applications. In a 2002 study, a comparison of single and multiple sieve methods for the determination of masticatory efficiency was conducted, whereas these methods have never been compared until this moment [33]. The multiple sieve method was reccomended when more detailed information on masticatory efficiency is required, as it provides a more accurate result.

Chewing gum

Poyiadjis and Likeman proposed an interesting way to measure masticatory efficiency, by using chewing gum (Wrigley's Freedent) [28]. The gum was dehydrated, and weighed after chewing. The after-chewing weight was compared to before-chewing one, and the weight reduction corresponded to the amount of sugar lost during chewing. Thus, the more sugar loss, the more efficient was the mastication. This methodology differed from the standard sieves method because the chewing gum could not be crushed by chewing and therefore the percentage of sugar loss during chewing was decisive for the value assigned to masticatory efficiency. According to the authors, the chewing gum proved to be excellent to test masticatory efficiency, allowing easy recovery after chewing. In a similar study, Anastassiadou,

Heath developed an objective test of mastication with chewing gums suitable for older people [34]. In this, the percentage of the original gum weight that was chewed out in a defined number of strokes was termed the masticatory effectiveness. Measuring the weight lost during chewing provided a simple test with chewing gum, especially important to be applicable to masticatory efficiency assessment of elderly people.

Hayakawa et al. also tested the use of chewing gum (color changing type) for the evaluation of masticatory efficiency [30]. The gum color changed as the masticatory process progressed and consisted of two layers. When the layers were mixed, the color changed from blue to red as a result of the reaction between the components (acid and dye). The new material was developed to fulfill two requirements:

(1) The color would change according to the degree of chewing executed and

(2) The material would not stick to the dentures. The gum was developed so that when chewed 5, 15, 30 and 45 times in dentate individuals, 25, 50, 75 and 100% of its total volume would become red, respectively. In their study, the authors concluded that gum color changing method could be used to quantitatively evaluate masticatory efficiency and was considered reliable enough to be used clinically.

According to Halazonetis et al. the chewing gum methodology, when used with chewing gum with different colors, provides a simple and safe evaluation of masticatory efficiency [35]. The authors tested the image analysis software View gum to be used with two color-tests, in a study that included 20 fully dentate volunteers. The software proved to be effectiveness because eliminated the drawbacks of the previously employed methods with chewing gum in two colors, showing up an important adjunct to masticatory efficiency evaluation using chewing gum in two colors. Schimmel et al. also investigated different assessment methods of two-colour chewing gum test for masticatory efficiency using a image analysis software [36]. The methodology to quantify the misture degree of a two-colour chewing gum was considered realiable and precise, reaffirming the importance of the combination of the method with chewing gums and image analysis.

Colorimetric method

Currently, the method known as beads (Colorimetry), which is still being investigated and improved upon, appears to be suitable in the field of masticatory efficiency investigations. A study by Santos et al. in 2006, was the first to report this methodology [37]. The material used for the masticatory efficiency evaluation was composed of bead capsules, approximately 1 mm in diameter, coated by polyvinyl acetate, which contained approximately 250mg beads, obtained by gelation ionotropic of polymer dispersions. These beads were pigmented with violet fuchsin, and consisted of a combination of lactose, microcrystalline cellulose, starch, sucrose, hydrogenated oil, water and basic fuchsin. The bead capsules were then chewed by the participants so that the fuchsin spread proportionally to the energy used in the grinding. The capsule coating properly contained the dye and the beads inside. In the laboratory, the content of the crushed beads was dissolved in water and its color intensity was measured using a spectrophotometer, resulting in a value of fuchsin concentration which corresponded to the masticatory efficiency.

In a study by Felicio et al. in 2008, the reliability of beads to test masticatory efficiency and its correlation with the masseter and anterior temporal electromyographic activity were investigated [38]. The results showed a high reliability of masticatory efficiency test and a significant correlation with electromyographic activity. In 2010, Mazzeto et al. evaluated the correlation between the results of two masticatory efficiency tests, one with sieves and another with colorimetric capsules, applied in a group of subjects with natural and complete dentitions [39]. The statistical results obtained showed a correlation between the two methods, both of which could be clinically applied to test masticatory efficiency. In the same year, Farias Neto et al. studied the effect of occlusion on masticatory efficiency of conventional complete denture wearers using the colorimetric method, this being the first application of this new methodology in relation to this treatment modality [2].

Subjective assessment

We should also highlight the use of subjective methods, such as questionnaires, to assess the individual self-perception as to their ability to chew [23]. For Feine, Lund the principal measures of masticatory efficiency should be based on the patients' perceptions. Slagter et al. evaluated the correlation between the masticatory efficiency using a questionnaire and objective tests, in complete denture wearers [23,25]. They concluded that the questionnaire method was rather weak compared to the objective tests and thus, dentists should not rely solely in subjective responses related to chewing problems, oral conditions and prosthesis quality in order to determine masticatory efficiency. Additionally, masticatory efficiency must be determined by scientifically proven objective tests, which may be supplemented by subjective tests, but never using the latter as a primary source of information. On the other hand, Bajoria et al. reported that while the objective quantification of the masticatory efficiency may result in a low value and not clinically significant, the subjective masticatory efficiency, which is an analysis by the patient about his mastication, may reflect a most relevant aspect. Thus, the combination of the two methods should be valuable for a thorough evaluation of masticatory efficiency [8,40].

Image analysis

Shi et al. proposed a masticatory efficiency study with soybean [41]. Soybean particles were chewed by 10 subjects with natural dentition and directly measured by a graphic scanner and a computer after different variations in the number of chewing cycles. A microscope was used to photograph the particles, that were amplified 14 times. A program developed by the authors calculated the diameter of the particles and descriptive statistical indices, including mean, median and standard deviation. After testing, it was noted that the method of direct measurement of the crushed soybean particle size provided important information and prevented errors that often occur with the sieves method. Additionally, Mowlana et al. developed a study aiming to validate the optical method by comparing it with the sieves method, using almonds as a natural test food [42]. The results for both methods showed similarity, allowing to conclude that the optical method was

easier and quicker to use, and also required less equipment skill than the sieves method.

Eberhard et al. (2012) conducted a study with the aim of presenting a valid and reproducible technique for evaluation of the masticatory efficiency through optical scanning in two dimensions (2-D), and enable comparison with the standard method of sieves [21]. Samples from crushed Optosil® chewed by healthy dentate were analyzed with the method of sieves and scanning. The scanning was performed using a conventional flatbed scanner (1200 dpi) and all scanned images were subjected to analysis of images in Image J editor. The scanning method was considered valid, simple and reproducible for the determination of the masticatory efficiency; however the authors explain that further studies are needed to test their ability in detecting small changes in masticatory efficiency.

B-carotene-containing gummy jelly

The development of an automated system for masticatory efficiency evaluation was proposed by Nokubi et al. [43]. The authors conducted the study in order to investigate the accuracy of a new system for direct masticatory efficiency measurement, by the use of a sticky gelatin containing beta-carotene. Using this method, the surface area of the crushed gelatin was calculated by measuring the glucose or beta-carotene concentration dissolved in water. A prototype device was developed, in which all operations presenting risk of errors were fully automated. The automatic system estimated the increase in crushed sticky gelatin surface area as a masticatory efficiency parameter of high precision after rinsing and dissolving each for 10 seconds. More, the grinding degree of the gelatin could be effectively represented as the masticatory efficiency by the increase in the test food surface area.

Discussion

A great variety of methodologies related to masticatory efficiency is currently found in the literature, however, important consideration should be given to the fact that very detailed protocols result in higher test complexity and reproducibility difficulties. One aspect of considerable importance for clinical studies is the sample standardization. Researches involving individuals with poor-fitting complete dentures may impair studies aimed to mastication analysis, so special attention should be given to the standardization with respect to complete denture properties such as retention, support and stability.

The use of sieves system to masticatory analysis is applied more than a century, being first reported by Gaudenz although old, it is a simple method that is scientifically reproduced until today, even being used as a standard in the development of new techniques [27]. Poyiadjis and Likeman describe a method that uses chewing gum, in which the weight reduction after chewing corresponded to the amount of sugar that was lost, indicating the masticatory efficiency [28]. When considering this method, the lack of adhesion of the material to the complete denture must be checked to not harm the analysis, as observed by Hayakawa et al. [30]. Since chewing gum is considered a sticky food, its application could possibly lead to loss in complete denture retention, being this also applied to B-carotene-containing Gummy Jelly method. This contains the most current method for the evaluation of masticatory efficiency, by means of an automated system. Nokubi et al. used a sticky gelatin containing beta-carotene that dissolved in water, and the amount of dissolved pigment was measured by photodiode voltage (light receptor) [43]. Among the methodologies mentioned in this review, only the B-carotene-containing Gummy Jelly was not applied to complete denture wearers, which can be explained because this is a very recent methodology.

The use of capsules containing the so called beads to evaluate masticatory efficiency is applied since 2006, and has been evaluated by Farias Neto et al. in conventional denture wearers [2]. It is an interesting method, however, it is still under methodological improvement.

Halazonetis et al. seeking the enhancement of technique to measure the masticatory efficiency with two-color gum developed new image analysis software (*ViewGum*), in order to simplify the chewing gum method [35]. The application of chewing gum together the image analysis aimed to improve the conventional technique, where the mixture of colors was verified visually, without specific equipment.

Some methodologies present the already mentioned limitation of relying on specific apparatus and training, as the image analysis, colorimetric and the B-carotene-containing Gummy Jelly methodologies. In addition, because these last two methods are very recent, more research needs to be carried out to further explore its reproducibility and applicability, particularly in complete denture wearers.

Despite the limitation of articles due the terms considered in this review, the addition of other studies by manual search in library/database was planned to complete the large amount of articles that refer the topic in question. Most of the included articles in this review were published in high impact journals, and, furthermore, some are classic articles of this topic. Special care was taken to add recent studies while this article was in process of submission for publication, in order to keep this review study updated.

Conclusion

It should be pointed out that simplicity and effectiveness are the two main requirements regarding the reproducibility of scientific as well as clinical methodology. Thus, despite the wide variety of new methodologies in the literature, the sieves method is currently considered the gold standard method to evaluation of conventional complete denture wearers masticatory efficiency, since it is the simplest, does not depend on specific devices (beyond the set of sieves), allows for a rational assessment, and it has been widely reproduced in various types of oral rehabilitation.

Finally, although there are various test foods utilized to evaluate masticatory efficiency [30,38,43], the almond, as natural test food [16,23,27,32,42] and the optocal (made from the molding material Optosil) as artificial test food, are the most constantly employed test foods to evaluate masticatory function in complete denture wearers, in natural dentition individuals, or even individuals rehabilitated with other prosthetic modalities [20-22,25,26,31].

References

1. Goiato MC, Garcia AR, Dos Santos DM, Zuim PR. Analysis of masticatory cycle efficiency in complete denture wearers. *Journal of Prosthodontics*. 2010; **19**: 10-13.

2. Farias Neto A, Mestriner W, Carreiro AFP. Masticatory efficiency in denture wearers with bilateral balanced occlusion and canine guidance. *Brazilian Dental Journal***.** 2010; **21**: 165-169.

3. Van Der Bilt A, Speksnijder CM, De Liz Pocztaruk R, Abbink JH. Digital image processing versus visual assessment of chewed two colour wax in mixing ability tests. *Journal of Oral Rehabilitation.* 2012; **39**: 11-17.

4. Van der Bilt A. Assessment of mastication with implications for oral rehabilitation: A review. *Journal of Oral Rehabilitation.* 2011; **38**: 754-780.

5. Vecchia MP, Regis RR, Cunha TR, de Andrade IM, da Matta JC. A randomized trial on simplified and conventional methods for complete denture fabrication. *Journal of Dentistry*. 2013; **41**: 133-142.

6. Witter DJ, Woda A, Bronkhorst EM, Creugers NHJ. Clinical interpretation of a masticatory normative indicator analysis of masticatory function in subjects with different occlusal and prosthodontic status. *Journal of Dentistry*. 2013; **41**: 443-448.

7. Liedberg B, Ekberg O, Owall B. Chewing and the dimension of the pharyngoesophageal segment. *Dysphagia*. 1991; **6**: 214-218.

8. Woda A, Hennequin M, Peyron MA. Mastication in humans: Finding a rationale. *Journal of Oral Rehabilitation.* 2011; **38**: 781-784.

9. Koshino H, Hirai T, Yokoyama Y, Tanaka M, Toyoshita Y, et al. Mandibular residual ridge shape and the masticatory ability in complete denture wearers. Nihon Hotetsu Shika Gakkai Zasshi. 2008; **52**: 488-493.

10. Geertman ME, Slagter AP, Van 'T Hof Ma, Van Waas Ma, Kalk W. Masticatory performance and chewing experience with implant-retained mandibular overdentures. *Journal of Oral Rehabilitation.* 1999; **26**: 7-13.

11. Feine JS, Lund JP. Measuring chewing ability in randomized controlled trials with edentulous populations wearing implant prostheses. *Journal of Oral Rehabilitation.* 2006; **33**: 301-308.

12. Carlsson GE. Masticatory efficiency: The effect of age, the loss of teeth and prosthetic rehabilitation. *International Dental Journal*. 1984; **34**: 93-97.

13. Bates JF, Stafford GD, Harrison A. Masticatory function: a review of the literature. III - Masticatory performance and efficiency. *Journal of Oral Rehabilitation.* 1976; **3**: 57-67.

14. Manly RS, Braley LC. Masticatory performance and efficiency. *Journal of Dentistry Research*. 1950; **29**: 448-462.

15**.** Glossary of prosthodontic terms: The Academy of Prosthodontics. The glossary of prosthodontic terms. *Journal of Prosthetic Dentistry*. 2005; **94**: 10-92.

16. Kapur KK, Soman SD. Masticatory performance and efficiency in denture wearers. *Journal of Prosthetic Dentistry*. 2006; **95**: 407-411.

17 - Gaudenz JV. Ueber die Zerkleinerung und Lösung von Nahrungsmitteln beim Kauakt. Archieves of Hygiene. *1901;* **39**: 230-251.

18. Buschang PH, Throckmorton GS, Travers KH, Johnson G. The effect of bolus size and chewing rate on masticatory performance with artificial test foods. *Journal of Oral Rehabilitation.* 1997; **24**: 522-526.

19. Kapur K, Soman S, Yurkstas A. Test foods for measuring masticatory performance of denture wearers. *Journal of Prosthetic Dentistry***. 1964; 14**: 483-491.

20. Ó Silva M, Zancopé K, Mestriner Junior W, Prado CJ, Neves FD. Avaliação da eficiência mastigatória por dois métodos: Colorimetria e tamises. *Revista De Odontologia Da UNESP*. 2011; **20**: 125-128.

21. Eberhard L, Schindler HJ, Ellmann D, Schmitter M, Rammelsberg P, et al. Comparison of particle-size distributions determined by optical scanning and by sieving in the assessment of masticatory performance. *Journal of Oral Rehabilitation.* 2012; **39**: 338-348.

22. Olthoff LW, van der Bilt A, Bosman F, Kleizen HH. Distribution of particle sizes in food comminuted by human mastication. *Archives of Oral Biology*. 1984; **29**: 899-903.

23. Demers M, Bourdages J, Brodeur JM, Benigeri M. Indicators of masticatory performance among elderly complete denture wearers. *Journal of Prosthetic Dentistry*. 1996; **75**: 188-193.

24. Toman M, Toksavul S, Saraçoglu A, Cura C, Hatipoglu A. Masticatory performance and mandibular movement patterns of patients with natural dentitions, complete dentures, and implant-supported overdentures. *International Journal of Prosthodontics*. 2012; **25**: 135-137.

25. Slagter AP, Olthoff LW, Bosman F, Steen WH. Masticatory ability, denture quality, and oral conditions in Edentulous subjects. *Journal of Prosthetic Dentistry*. 1992; **68**: 299-307.

26. Mendonça DB, Prado MM, Mendes FA, Borges TDF, Mendonça G. Comparison of masticatory function between subjects with three types of dentition. *International Journal of Prosthodontics*. 2009; **22**: 399-404.

27. Gunne H-SJ. Masticatory efficiency and dental state. A comparison between two methods. *Acta Odontologica Scandinavica*. 1985; **43**: 139-146.

28. Poyiadjis YM, Likeman PR. Some clinical investigations of the masticatory performance of complete denture wearers. *Journal of Dentistry*. 1984; **12**: 334-341.

29. Okiyama S, Ikebe K, Nokubi T. Association between masticatory performance and maximal occlusal force in young men. *Journal of Oral Rehabilitation.* 2003; **30**: 278-282.

30. Hayakawa I, Watanabe I, Hirano S, Nagao M, Seid T. A simple method for evaluating masticatory performance using a color-changeable chewing gum. *International Journal of Prosthodontics.* 1998; **11**: 173-176.

31. Edlund J, Lamm CJ. Masticatory efficiency. *Journal of Oral Rehabilitation.* 1980; **7**:123-130.

32. Al-Ali F, Heath MR, Wright PS. Simplified method of estimating masticatory performance. *Journal of Oral Rehabilitation.* 1999; **26**: 678-683.

33. Van der Bilt A, Fontijn-Tekamp FA. Comparison of single and multiple sieve methods for the determination of masticatory performance. *Archives of Oral Biology*. 2004; **49**: 193-198.

34. Anastassiadou V, Heath MR. The development of a simple objective test of mastication suitable for older people, using chewing gums. *Gerodontology*. 2001; **18**: 79-86.

35. Halazonetis DJ, Schimmel M, Antonarakis GS, Christou P. Novel software for quantitative evaluation and graphical representation of masticatory efficiency. *Journal of Oral Rehabilitation.* 2013; **40**: 329-335.

36. Schimmel M, Christou P, Herrmann FR, Müller F. A two-colour chewing gum test for masticatory efficiency: development of different assessment methods. *Journal of Oral Rehabilitation.* 2007; **34**: 671-678.

37. Santos CE, Freitas O, Spadaro ACC, Mestriner W. Development of a Colorimetric System for Evaluation of the Masticatory Efficiency. *Brazilian Dental Journal*. 2006; **17**: 95-99.

38. Felício CM, Couto GA, Ferreira CLP, Mestriner W. Confiabilidade da eficiência mastigatória com beads e correlação com a atividade muscular. *Pró-Fono Revista de Atualização Científica*. 2008; **20**: 225-230.

39. Mazzetto MO, Hotta TH, Petenusci SO, Mestriner-Junior W, Yamasaki MK, et al. Eficiência mastigatória: Análise de correlação de dois testes. *Revista Gaúcha de Odontologia.* 2010; **58**: 319-322.

40. Bajoria AA, Saldanha S, Shenoy VK. Evaluation of satisfaction with masticatory efficiency of new conventional complete dentures in edentulous patients-a survey. *Gerodontology*. 2012; **29**: 231-238.

41. Shi CS, Guan QY, Guo TW. Masticatory efficiency determined with direct measurement of food particles masticated by subjects with natural dentitions. *Journal of Prosthetic Dentistry*. 1990; **64**: 723-726.

42. Mowlana F, Heath MR, Van der Bilt A, Van der Glas HW. Assessment of chewing efficiency: a comparison of particle size distribution determined using optical scanning and sieving of almonds. *Journal of Oral Rehabilitation.* 1994; **21**: 545-551.

43. Nokubi T, Yasui S, Yoshimuta Y, Kida M, Kusunoki C. Fully automatic measuring system for assessing masticatory performance using b-carotene-containing gummy jelly. *Journal of Oral Rehabilitation.* 2013; **40**: 99-105.