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Review

Assessment of masticatory performance by means of a color-changeable chewing gum

Agnieszka Tarkowska [a,*], *Lukasz Katzer* [a], *Marcus Oliver Ahlers Priv.-Doz. Dr. med. dent., Senior Lecturer* [a,b]

[a] *CMD-Center Hamburg-Eppendorf, Hamburg, Germany*
[b] *University Medical Center Hamburg-Eppendorf, Center for Dental and Oral Medicine, Department of Prosthetic Dentistry, Hamburg, Germany*

ARTICLE INFO

Article history:
Received 15 October 2015
Received in revised form
20 March 2016
Accepted 14 April 2016
Available online xxx

Keywords:
Masticatory performance
Masticatory efficiency
Color changeable chewing gum
Occlusal function
Postoperative monitoring
Gerodontology

ABSTRACT

Purpose: Previous research determined the relevance of masticatory performance with regard to nutritional status, cognitive functions, or stress management. In addition, the measurement of masticatory efficiency contributes to the evaluation of therapeutic successes within the stomatognathic system. However, the question remains unanswered as to what extent modern techniques are able to reproduce the subtle differences in masticatory efficiency within various patient groups. The purpose of this review is to provide an extensive summary of the evaluation of masticatory performance by means of a color-changeable chewing gum with regard to its clinical relevance and applicability.

Study selection: A general overview describing the various methods available for this task has already been published. This review focuses in depth on the research findings available on the technique of measuring masticatory performance by means of color-changeable chewing gum. Described are the mechanism and the differentiability of the color change and methods to evaluate the color changes. Subsequently, research on masticatory performance is conducted with regard to patient age groups, the impact of general diseases and the effect of prosthetic and surgical treatment.

Results: The studies indicate that color-changeable chewing gum is a valid and reliable method for the evaluation of masticatory function.

Conclusion: Apart from other methods, in clinical practice this technique can enhance dental diagnostics as well as the assessment of therapy outcomes.

Contents

* *Corresponding author at*: CMD-Center Hamburg-Eppendorf, Falkenried 88 (CiM), 20251 Hamburg, Germany. Tel.: +49 40 46776107; fax: +49 40 46776108.
E-mail address: Agnieszka.Tarkowska@cmd-centrum.de (A. Tarkowska).

http://dx.doi.org/10.1016/j.jpor.2016.04.004
1883-1958/

1. Introduction

Scientific literature concerning masticatory performance is divided into coverage of three core issues: firstly, the relevance of masticatory efficiency regarding the human organism as a whole; secondly, the methods for measuring chewing performance; and thirdly, the factors influencing masticatory efficiency.

New topics concerning the link between masticatory performance and the functions of the entire human organism have constantly been described. In this context, sufficient masticatory efficiency seems to affect not only gastrointestinal functions, but also to simultaneously influence patient's nutritional status and quality of life [1–3]. A significant association of decreased masticatory performance in children with higher incidence of being underweight has been described in a study [4]. Moreover, the influence of mastication on cognitive functions has been discussed and its anti-stress effect has been detected [5–8]. One study suggests that the chewing process is able to increase cerebral blood flow, simultaneously enhancing the oxygen supply to the brain and thereby activating numerous cortical areas [9]. Hence an improvement in learning processes during chewing on chewing gum has been observed [10].

1.1. *Evaluation methods*

Several objective and subjective measurement methods have already been developed to quantify and thereby to evaluate masticatory performance. Sieving of chewed natural or, respectively, artificially produced food, and subsequent determination of the average particle size is still considered to be the "gold standard" for the quantification of masticatory efficiency [11,12]. The complex sieving process has gradually been replaced through a further development of this method. For this purpose, chewed particles are scanned and the average size is calculated by a suitable software program [13–15].

An alternative method is based on the colorimetric measurement of the dye release after chewing raw carrots [16]. Other procedures determine the percentage of sugar chewed out of a chewing gum [17]. In addition, photometric measurement of water-soluble dye concentration has been taken after test gelatin pieces or pigment-coated granules have been chewed [18,19]. Finally, a method based on a two-color chewing gum has been established in which the mixing degree has been determined by a comparison with a color scale, a scan, or later by specially developed software [20–25]. The application of two-color paraffin wax cubes follows a similar principle. The evaluation implies visual assessment or a scan-technique for more precise color mixing results [26]. So far, none of the described methods is routinely used in dental practices.

In general, a method suitable for the task can serve to objectively and reproducibly evaluate therapeutic goals concerning the improvement of individual masticatory performance. A measurement at the beginning, a comparative measurement at the end of a treatment, as well as additional measurements during the rehabilitation process can allow for an objective evaluation of the treatment outcome. Therefore, a method is required that combines high precision, practicability in the dental daily routine, and limited temporal or technical requirements.

Apart from the described methods, a measurement technique by means of a color-changeable chewing gum seems most likely to fulfill those requirements due to its simplicity and its reported superior differentiability. This method has been developed by a Japanese research group to allow for a simple measurement of masticatory performance through the color change of the chewing gum. The material is specially developed for that purpose (Masticatory Performance Evaluating Gum XYLITOL; Lotte Co., Ltd., Tokyo, Japan).

This review concentrates on the scientific findings regarding this color-changeable chewing gum. The research of literature using specific search terms is displayed in Table 1.

1.2. *Chemical mechanism, validity, reliability*

The first publication concerning the principle of color-change in chewing gum was published in 1989. The raw material consisted of phloxine ($C_{20}H_2Br_4Cl_4Na_2O_5$) and sodium bicarbonate ($NaHCO_3$) at a ratio of 4:1. Phloxine is a dye that develops red color under alkaline conditions. Alkaline sodium bicarbonate enables this reaction during mastication [27]. As the composition of the components was associated with high adhesion, the chewing gum did not seem to be suited either for

Please cite this article in press as: Tarkowska A, et al. Assessment of masticatory performance by means of a color-changeable chewing gum. J Prosthodont Res (2016), http://dx.doi.org/10.1016/j.jpor.2016.04.004

Table 1 – Literature research up to December 31, 2015.

Search terms	Databases	Articles found
„masticatory AND efficiency“	PubMed LIVIVO DIMDI	421 972 500
„masticatory AND performance”	PubMed LIVIVO DIMDI	582 626 838
“color AND changeable AND chewing AND gum”	PubMed LIVIVO DIMDI	22 14 30
	Manual Screening of titles and abstracts	
Publications promising to match the scope of this review	85	
	Reading and evaluation of full articles	
Publications matching the scope	65	

patients wearing dentures or for those with limited salivation. Resin additives provide lower adhesion, but simultaneously result in a slightly harder chewing gum material. In the following, the modified chewing gum has been tested for its applicability and reproducibility on natural dentate patients and complete denture wearers in a pilot study [28].

Hence, subsequently another diagnostic chewing gum was developed based on a different principle. Its concept aimed at the prevention of saturation and therefore at a better differentiability of the results. Thereby, the color reaction does not result from mixing the two components, but from a long-term chemical reaction. This reaction is based on the characteristics of blue, yellow, and red dyes in combination with added citric acid. Amongst the three dyes, the red dye is pH-sensitive and develops its color only under neutral or alkaline conditions. However, the additionally added citric acid maintains a low pH in the chewing gum before chewing. Hence the red dye initially remains invisible and the color of the chewing gum is yellowish-green prior to mastication. During mastication, the blue and yellow dye seep into saliva while at the same time the citric acid washes out, leading to an increase of the pH of the chewing gum. Hence, the red dye appears and the chewing gum turns red gradually.

Subsequent measurements of the intensity of the color change in the chewing gum were necessary to transform the chewing gum into a diagnostic method. As it turned out, due to its high grade of differentiability, this new method seems to be suitable for the measurement of masticatory performance in all variations of dental status. In addition, the color-changeable chewing gum enables a detailed demonstration of the differences in masticatory efficiency in fully dentate patients [29].

In conclusion, the studies investigated in Section 2 rely on this kind of color-changeable chewing gum.

1.3. *Evaluation methods*

For the measurement of the color change, the chewing gum is placed between two polyethylene films and flattened to a thickness of 1.5 mm by two glass plates. The subsequent measurement is undertaken at several previously defined points and results each time in a mean value reproducing patients' and, respectively, healthy volunteers' masticatory performance.

Color analysis is performed by the measurement of the color differences before and after the mastication process. In most studies colorimetric measurement of masticatory performance based on the $L^*a^*b^*$ color space model was applied to ensure a valid and reliable evaluation. The $L^*a^*b^*$ model matches human perception of lightness and color differences by its coordinates. In this way, the results of the measurement remain device independent [30]. In the $L^*a^*b^*$ model, L^* represents the lightness, the a^* axis the red/green opponent colors, and the b^* axis the yellow/blue opponent colors [31]. Applied to measurement of color shades of chewing gum before chewing, the values of the $L^*a^*b^*$ color space revealed L^*: 72.3, a^*: −14.9, and b^*: 33.0. After chewing, the values measured by means of a colorimeter (CR-13; Konica Minolta Sensing, Tokyo, Japan) were converted into ΔE according to the following formula [32]:

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$$\Delta E = \sqrt{(L* - 72.3)^2 + (a* + 14.9)^2 + (b* - 33.0)^2}$$

ΔE represents the mean difference between two colors in the CIELAB color space, calculated before and after chewing. Hence ΔE shows the color change and therefore expresses the efficiency of the masticatory process. The relationship between $L^*a^*b^*$ color space model and ΔE shows a significant correlation (Fig. 1) [32].a^* value as well as ΔE are ordinal variables so that the distances between the analyzed characteristic values are not quantifiable and therefore cannot be used for parametric statistics. For the use of values as ratio scales ΔE can be converted into numbers of chewing strokes using non-linear regression expression [29]:

$$\Delta E = 73.2 - \frac{2.85 \times 10^7}{1 + e^{9.95 \times 10^{-3}(N + 1.35 \times 10^3)}}$$

In most studies, solely a^* axis values (the development of the red dye) have been measured and used for the assessment of masticatory performance as the most significant parameter [27,28,33–44].

Apart from colorimetric measurement, several working groups developed color scales. Some of these color scales were developed only by visual inspection [44] (Figs. 2 and 3). Furthermore, the comparability with the $L^*a^*b^*$ model as well as clinical relevance have been verified [32]. Numerical analysis by means of a colorimeter has therefore been assigned to analogous color shades, and in this way the color scales have been developed (Fig. 4). The correlation between a^* axis values and the color shades has been confirmed, and validity and reliability have repeatedly been tested and confirmed. Numerous further groups used color scales to assess color change [45,47–50]. Thus, the method appears to be suitable for clinical application [32,44–50].

2. Measurement of masticatory performance in different application areas

Following the development of the color-changeable chewing gum based on different dyes and added citric acid as described in Section 1.2, several clinical studies were conducted that investigated different topics.

2.1. *Effects of various prosthetic treatments*

Apart from investigations into masticatory performance in patient groups of different ages (as described below), several studies determine age-independent masticatory efficiency with regard to different prosthetic treatment possibilities.

The applicability of color-changeable chewing gum to assess masticatory performance has initially been determined in patients with implant-supported prostheses. The results have simultaneously been compared with those of fully dentate test persons. An improved stability and an increased masticatory performance have been observed after treatment with implant-supported prostheses [51].

Masticatory performance has also been examined by means of the color-changeable chewing gum with regard to the treatment with implant-supported single crowns in subjects with tooth agenesis. The results confirm the improvement of masticatory efficiency due to the treatment [33].

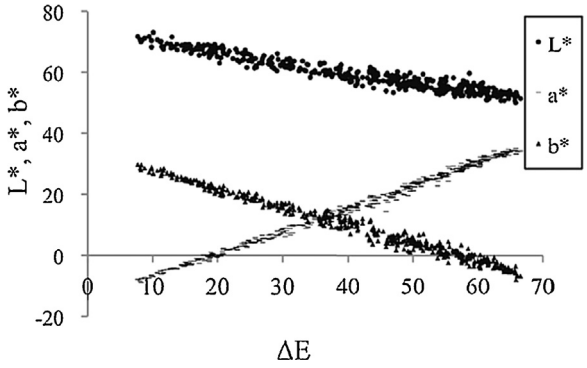

Fig. 1 – Linear relationship between ΔE and L^*, a^*, b^*. Corresponding linear regression expressions: $L^* = -0.32\Delta E + 72.57$ ($R^2 = 0.92$, $P < 0.001$); $a^* = 0.75\Delta E - 14.59$ ($R^2 = 0.99$, $P < 0.001$), $b^* = -0.59\Delta E + 33.51$ ($R^2 = 0.98$, $P < 0.001$) [32].

Another study investigates the impacts of palatal coverage on bolus formation during mastication and swallowing, as well as the subsequent adaptive changes. The results show a significant deterioration of the masticatory performance after insertion of the palatal coverage in fully dentate adults [52].

The studies determine the potential of color changeable gum to evaluate the effect of prosthetic therapies on masticatory performance and thus to contribute to improve therapy strategies in practice.

2.2. *Measurement of the outcome of surgical therapy*

The characteristics of the color-changeable chewing gum have been used early for the assessment of masticatory performance before and after surgical procedures in the stomatognathic system.

Masticatory efficiency has been determined inter alia in postoperative conditions in patients with squamous cell carcinoma rehabilitated with osseointegrated implants, compared both to healthy volunteers with implants and also to fully dentate test persons. It has been revealed that the integrity of the hypoglossal nerve and thus the maintained innervation and the mobility of the remaining tongue after surgical intervention are decisive for the later efficiency of masticatory function [53].

Another research group conducts a long-term study on articulation and masticatory performance after glossectomy of tongue carcinoma. Continuous follow-up examinations reveal significant impairment of articulation and masticatory efficiency one month after surgical intervention. In contrast, postoperative improvement with subsequent plateau after six to twelve months has been observed. Moreover, greater impairment of masticatory performance has been observed after hemiglossectomy than after partial glossectomy [35].

The applicability of the color-changeable chewing gum has been examined by a further scientific group through the measurement of masticatory efficiency in patients after mandibulectomy. A positive correlation between color-changeable

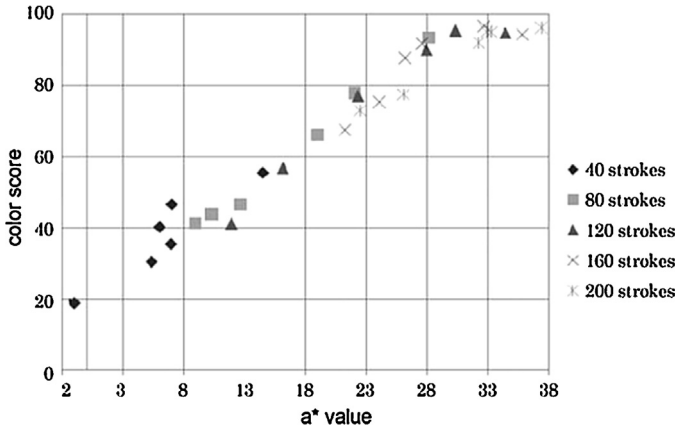

Fig. 2 – Correlation between a^* values and the mean color shade according to the number of chewing strokes. Pearson's correlation coefficient between a^* values and mean color scale values: 0.979 [44].

Fig. 3 – Color-changeable chewing gum (Masticatory Performance Evaluating Gum XYLITOL; Lotte Co., Ltd., Saitama, Japan) and color scale consisting of five intermediate colors resulting from the color changes after 20–200 chewing strokes, as researched in [44].

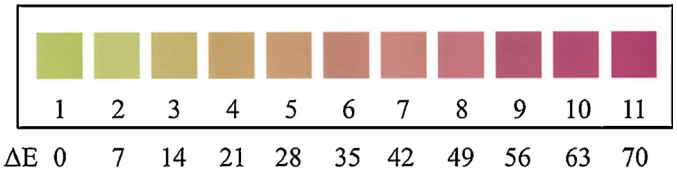

Fig. 4 – Established alternative and more differentiated color scale according to the evaluation presented in Fig. 1. The conversions of ΔE into L^*, a^* and b^* values were based on linear regression analysis. The ΔE values from 0 to 70 were divided in intervals of 7 ΔE, which hence were converted into a total of 11 color shades [32].

chewing gum, gummy jelly (gelatin cubes), and a modified Sato's questionnaire to assess patients' ability to chew different types of food has been observed [54,55]. Therefore, the chewing gum seems to be a suitable procedure to assess masticatory performance after mandibulectomy [49]. Most relevant risk factors associated with masticatory dysfunction after maxillectomy have been subsequently determined by the same working group. The analysis of the results verifies the number of anchor teeth (≤2) and the extent of soft palate defect as significant risk factors for the development of masticatory dysfunction [50].

These studies determine that by means of color-changeable gum the effect of the respective oral surgery therapies on the masticatory performance can be assessed, evidently providing decisive information on the functional outcome of the respective therapies.

2.3. *Factors influencing masticatory performance*

The correlation between habitual jaw movements during mastication and masticatory performance has been examined on 45 fully dentate patients by means of the color-changeable

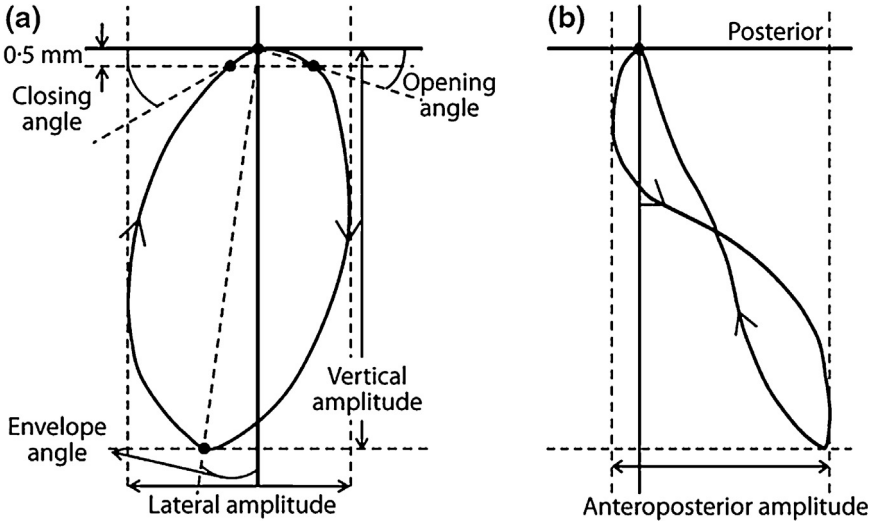

Fig. 5 – Image of the mandibular movement in the frontal and sagittal plane with marked parameters for the characterization of the movement. Characterization was based on chewing strokes chosen as representative in research [56].

chewing gum. Mandibular movement analysis has been performed by an opto-electric system with six degrees of freedom (Gnathohexagraph system, version 1.31; Ono Sokki, Kanagawa, Japan). The study measures the amplitude (vertical, lateral, and anteroposterior), the duration of jaw opening and jaw closing, as well as opening and closing angles, measurable by a slice level delineated 0.5 mm below the maximal intercuspal position (Fig. 5). The analysis indicates small closing angles and maximum closing velocities as the most important parameters with significant influence on masticatory performance [56].

In an investigation on the impact of occlusal contacts on mixing ability it has been determined that actual occlusal contacts and near occlusal contact areas (interocclusal distance up to 200 μm) are decisive with regard to mixing ability [57].

In another study, the occlusal contact area as well as bite force and masticatory performance has been determined before and up to two years after orthognathic surgical correction of mandibular prognathism. The results have been compared with those of healthy test persons. Prior to surgery, patients suffering from prognathism show reduced bite force, fewer occlusal contacts, and inferior masticatory performance in comparison to healthy test persons. After surgical correction improvement of all parameters has been observed. Compared to healthy volunteers, however, the patients even two years after surgical intervention do not achieve equal bite force and quality of occlusal contacts. Nonetheless, with regard to the scientific issue of this review it is crucial that the masticatory efficiency measured two years after the operation nearly resembled that of healthy test persons. The lack of measurements of masticatory performance would therefore incorrectly and unfavorably describe the functional results of the surgical therapy [42].

Another research group examined the relationship between tongue and lip functions and masticatory performance in 51 young dentate adults. As a result, the authors determined that while chewing brittle food (such as peanuts), masticatory performance is significantly correlated with maximum tongue pressure and lip function. This mechanism can be observed while chewing hard and elastic foods (such as test gummy jelly) [58].

These studies confirmed that the use of color-changeable gum provides valuable insight in the parameters that influence masticatory performance. The information can be used to design or improve dental treatment concepts. Future areas of application could include – for example – the masticatory efficacy of CAD/CAM-generated occlusion in comparison to restorations manufactured by hand.

2.4. *Correlation between general diseases and masticatory performance*

The link between masticatory efficiency and general medical symptoms and diseases beyond dental issues has also been examined by means of color-changeable chewing gum.

Decreased masticatory performance has already been detected in previous studies in patients with malocclusions [59]. Furthermore, the effect of decreased masticatory efficiency on gastrointestinal digestive function has been analyzed. For this purpose, female patients with malocclusions as well as healthy female test persons participated in the study. Gastric emptying rate has been measured by means of a ^{13}C-acetate breath test. As a result, the retarding effects of malocclusion and hence of those of decreased masticatory performance on gastric emptying have been described. Masticatory efficiency seems thereby to play a considerable role not only in actual mastication but also in general digestive processes [34].

Furthermore, the correlation between masticatory performance and type 2 diabetes has been investigated. The results of the study determined that high masticatory efficiency and

slow eating could prevent the occurrence of diabetes. Obviously, masticatory performance can be a direct factor in the etiology of type 2 diabetes. The metabolic disease has been diagnosed for the first time within the framework of this study in 7.7% of male and 2.4% of female participants [60].

An unbalanced diet, frequently associated with decreased masticatory performance, may result in the reduction of muscle mass, muscle strength, and in general physical capability [2,61]. The relationship between masticatory performance measured by means of the color-changeable chewing gum and the occurrence of sarcopenia in community-dwelling elderly persons has therefore been analyzed in another study [45]. In addition, the correlation between masticatory efficiency and heart rate variability indices (high and low sympathetic activity) has been observed. The patient group with high sympathetic activity (LF $\geq$ 49.6) shows a significantly decreased masticatory efficiency than the one with low sympathetic activity. Therefore it is assumed that reduced masticatory performance may be a risk factor for the development of the high sympathetic activity [37].

The results from these studies proved that by means of color changeable gum the importance of masticatory function in internal medicine can be assessed – with results that lead to new treatment strategies.

2.5. *Masticatory performance in patient groups of different ages*

2.5.1. *Elderly*

Masticatory performance, the essential factors influencing the efficiency of the mastication process, as well as symptoms correlated with decreased masticatory performance of the elderly population have been examined. According to the studies edentulous patients (age-independent), as well as their dental treatment with complete dentures represent the most frequent dental findings in the majority of the investigations [43,47,62]. The correlation between masticatory performance, general health, and the quality of life of the elderly are another focus of these studies [39,48].

The comparison of subjective and objective masticatory performance measurement methods in patients with previous and new complete dentures has been shown in a study. With the exception of the sieving method, all applied methods (color-changeable chewing gum, patient satisfaction questionnaire, and food questionnaire) show an (not significant) improvement in masticatory performance after the insertion of the new dentures. The results of the color-changeable chewing gum method and those of the questionnaires show a significant correlation [43].

Another study analyzes the subjective perception of the patient's quality of life after replacement of complete dentures. For this a self-assessment questionnaire has been completed before and after the replacement with the new complete dentures. In addition, the relevance of masticatory performance has also been verified by chewing color-changeable chewing gum before and after the treatment. The results show that a sufficient retention of the lower dentures and an adequate esthetics and phonetics have the greatest influence on the patient's quality of life. In addition, an improvement of masticatory performance has been described after the treatment. However, no significant correlation between masticatory efficiency and the results of the questionnaire have been observed [62].

Furthermore, the physical performance in edentulous older persons with complete dentures has been analyzed with regard to their masticatory performance. In order to assess the patient's capability to participate in daily life activities, the color-changeable chewing gum has been measured as well as muscle strength and static balance. In female participants there is no significant correlation between their masticatory efficiency and different physical capabilities. Male participants, however, exhibit a positive and significant correlation between the masticatory efficiency and the one-leg standing time with eyes open parameter (OLST). Therefore, masticatory performance seems to be associated with static balance [47].

Irrespective of the patient's dental status, color-changeable chewing gum has been used for an objective evaluation of masticatory performance in community-dwelling elderly persons. The results show a significant, positive correlation between masticatory performance, the number of residual teeth, maximum bite force, and the questionnaire outcome assessing the patient's subjective masticatory ability in both female and male participants [38]. A further study verifies the association between masticatory efficiency in elderly persons in geriatric clinical settings, and their nutritional status, dental status, physical and cognitive functions, as well as depressive status [39]. Similar findings have been shown in a study with community-dwelling elderly [48]. The patients were divided into two groups according to the evaluation of their masticatory performance. 105 patients with decreased masticatory efficiency (scores of 1–3) represented the first, whereas 164 patients with high masticatory performance (scores of 4–5) were classified in the second group. The evaluation of the results showed that those in the group with low masticatory efficiency were older, had a significantly greater subjective sense of chewing difficulty ($P = 0.005$), and significantly fewer teeth ($P < 0.001$) than those in the group with high masticatory efficiency. In addition, the number of remaining teeth had a strong influence on the ability to chew different types of foods (Fig. 6).

The practicability of a new comprehensive method with non-invasive measurement of subclinical diseases within a general health screening has been analyzed in elderly persons aged 85 and above. The medical examination has been undertaken by geriatricians, dentists, psychologists, sociologists, and epidemiologists. In this study, the color-changeable chewing gum has been successfully used for the evaluation of masticatory performance [63].

The studies cited in this section confirm the feasibility of the assessment of masticatory function by means of the color changeable gum in elderly patients, even with compromised dental situations.

2.5.2. *Children*

Comparatively fewer studies deal with the measurement of masticatory performance by means of the color-changeable chewing gum in children. The correlation between deciduous and transitional dentition and masticatory efficiency, as well as adaptability alteration during dental development appears to be most important in this connection.

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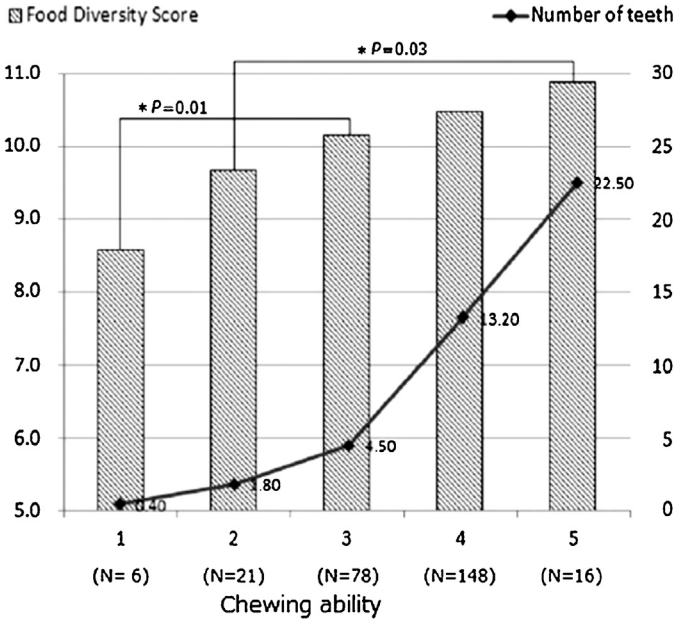

Fig. 6 – Diagram illustrating the significant correlation between chewing ability and the number of teeth in community-dwelling elderly [48].

Differences between the number of chewing strokes per minute during chewing on chewing gums with various volumes and hardness has been examined by a Japanese working group in children with different dental stages. This study examines to what extent the number of chewing strokes influences masticatory performance. It has been proven that masticatory adaptability to different chewing gum volumes and hardness improves with children's dental development. However, the group of children aged 11–13 represents an exception. In this case, masticatory performance decreases for a short time with the loss of deciduous molars. In addition, there is no significant correlation between the number of chewing strokes and masticatory performance in this group [40]. Factors with significant influence on masticatory efficiency have furthermore been analyzed by color-changeable chewing gum in pre-school children (aged 4–6), school children (aged 9–11), and adults (aged 24–36). The rate of mandibular movement is the most important factor in all three groups. In addition, biting force and body weight influence masticatory performance in school children, while occlusal contact area and biting force do so in adults [36].

Another study determined the impact of regular gum chewing on maximal bite force and masticatory performance. An exercise group of children had been instructed to chew the exercise gum daily over several weeks, while a control group had been instructed not to chew gum at all. At the beginning of the study there was no difference in masticatory performance between these two groups. After four weeks maximal bite force as well as masticatory performance increased significantly in the exercise group and remained elevated for several weeks even after the end of the study [41].

These studies determined that color changeable gum can be used to assess masticatory function in children, too, especially – but not exclusively – with regard to the effect of the loss and replacement of teeth.

Altogether, the articles cited in this review demonstrate a wide range of potential application areas of the color changeable chewing gum. The results of the studies conducted so far indicate that masticatory performance appears to play an important role in different functions of the stomatognathic system and – beyond this organ – therefore influences the whole organism in various ways. The introduction of this method in clinical practice therefore appears justified in situations where the assessment of masticatory function is clinically relevant in the patient's therapy.

3. Discussion

3.1. *Limits of the comprehensiveness of the reviewed literature*

Although the information researched, structured and presented in this review is extensive, there are still limitations, primarily in the coverage of the development of the method from the idea to the prototype of the currently used color-changeable chewing gum. Since several previous articles have been published only in Japanese, no complete overview can be presented here.

3.2. *Factors limiting the validity of the reviewed studies*

Furthermore, there are limitations in the validity of numerous studies evaluated in this review. These limitations result either from an absent comparison with other measurement methods, or from a low degree of evidence due to unclear

inclusion and exclusion criteria and/or missing control groups [64]. There are no randomized clinical studies amongst the publications included in this review. In addition, the majority of the articles described are non-controlled studies.

Also, patients suffering from temporomandibular dysfunctions (TMD) have frequently been specifically excluded from the studies cited [29,32,34,57]. More often, this group of patients was not per se left out by respective exclusion criteria, but rather by the study stating that there were no cases of TMD among the participants [28,33,36,40,42,43,47,56]. This appears surprising as currently applicable Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) classify all Temporomandibular Disorders into three groups, i.e. muscle disorders, disc displacements and joint disorders. The prevalence in the population was reported to be 9.7% for the first group, 11.5% for the second and 2.6% for the third group [65]. Hence the prevalence of TMD is far too high to allow for the chance of not including a single patient suffering from TMD in a study group of more than 100 participants. In conclusion, patients suffering from TMD obviously must have been unidentified among the patients included in the studies. It remains unclear if undetected TMD-patients included in the studies may have altered the results.

On the other side, due to the prevalence of TMD, the examination of masticatory performance in particular in patients suffering from temporomandibular complaints seems to be practically relevant and appropriate. Unfortunately, no study evaluated the effects of the loss of hard tooth substance on masticatory performance. Bruxism, frequently associated with TMD complaints, as well as other abrasive/erosive processes has neither been examined with the color-changeable chewing gum nor with the other measurement methods described above. Changes such as decreased vertical dimension or altered occlusion, as well as possible therapeutic options, had also not been investigated with regard to masticatory performance.

3.3. *Factors limiting the comparability of the reviewed studies*

Within numerous studies the method has furthermore been modified into different versions. The number of chewing strokes varied between 50 and 100 [28,43,62], while 60 strokes were described as being optimal in most articles [29,52,57]. The counting of the chewing strokes has partially been abandoned. Instead, time restrictions for the mastication process (30 s to 3 min) have been chosen [36,39–41,47–50]. Therefore, there is still no described uniform measurement method applicable to all groups of patients.

Moreover, a discrepancy concerning the evaluation of the measurement approach has been observed. The color change of the chewing gum has been measured by means of a colorimeter in most publications. Several working groups, however, developed special color scales to reduce the technical and temporal expenditure of the measurement [32,44–50]. In fact, the validity and reliability of this evaluation method compared with the colorimeter measurements have been proven. The question remains unanswered whether the color scales are differentiated enough to reproduce the fine differences in masticatory efficiency, e.g. in fully dentate patients or in ‘‘before and after comparisons’’ following moderately invasive treatment methods. In this regard, it appears useful to apply color scales in cases in which a significant difference is expected and a large sample size allows detection of significant differences statistically. The advantages of this method are its simplicity and hence suitability for large research studies or for the application by non-dental professionals. The standardized colorimetric measurement approach, on the other hand, should be used in order to present more detailed outcomes. In this manner, small differences measured in a large sample sizes of patients allow the detection of significant effects.

The described method seems applicable and is widely published. However, at present it is very difficult to obtain the color-changeable gum outside of Japan. Verifying the results in Europe is therefore nearly impossible. It therefore seems desirable to conduct further studies using the method in other continents, too.

3.4. *Application of the technique in clinical practice*

The studies compiled for this review have demonstrated the effects of masticatory performance on numerous functions of the stomatognathic system as well as on those of the whole organism.

The studies determine that the method was able to determine the success of prosthetic restorations. Also, the method was successfully used to monitor pre- and postoperative masticatory performance before and after oral surgical interventions and thus provide valuable information in the assessment of different surgical techniques. It is surprising that the evaluation of masticatory function per se is still not implemented in the dental practice as a diagnostic procedure.

Hence it appears desirable to establish an adequate, valid, and reproducible measurement method that can routinely be applied in the dental practice. However, the majority of the methods for measuring masticatory performance available so far require a large outlay in technology and time. The description of the methodology compiled in this review concerning the applicability, validity, and reliability of color-changeable chewing gum outlines the practical advantages of this method. The clinical studies cited affirm the applicability of the masticatory performance evaluation regarding clinical issues. The method hence appears to be reliable and feasible, and is able to provide the required information on masticatory performance in clinical dentistry.

4. Conclusion

Existing studies indicate that the assessment of masticatory function is relevant in dentistry and oral surgery as well as in certain medical situations. Amongst the different techniques available, the color changeable gum appears to be the easiest to use in practice. For the evaluation of the masticatory performance by means of the color changeable gum both techniques described in this review (visual matching with published color scales vs. colorimetric measurement) can be used.

The evaluation should be based on color scales if the sample sizes are large enough to detect even tiny differences. Also the evaluation based on color scales can be carried out by

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non-dental professionals (e.g. in a medical office). On the other hand, the standardized colorimetric measurement approach should be if more detailed individual results are essential, either in individual dental treatment or in studies with small sample sizes.

There are studies asserting the validity of both evaluation techniques, but investigations based on more sophisticated designs, especially randomized clinical trials, remain to be published.

Conflict of interest

The authors report no conflicts of interest related to this review.

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Please cite this article in press as: Tarkowska A, et al. Assessment of masticatory performance by means of a color-changeable chewing gum. J Prosthodont Res (2016), http://dx.doi.org/10.1016/j.jpor.2016.04.004