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Assessment of masticatory performance: Current methods and clinical applications

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ABSTRACT

Background: Masticatory performance is a key indicator of oral function and the success of prosthodontic rehabilitation, particularly in patients with tooth loss. Reduced masticatory function can impair food comminution and negatively affect digestion and quality of life. Properly designed dental prostheses can restore masticatory efficiency by optimizing force distribution, enhancing food fragmentation, and improving coordination within the masticatory system, whereas poorly fitting prostheses may compromise function and comfort. Consequently, the assessment of masticatory performance has become an essential parameter in evaluating functional recovery following prosthetic treatment. Review context: Masticatory performance is defined as the degree of food comminution achieved under standardized conditions, distinct from masticatory efficiency, which refers to the number of chewing cycles required to reach a specific masticatory outcome. Current assessment methods include both subjective and objective approaches. Subjective methods rely on questionnaires and self-reported measures to capture patients' perceived chewing ability, while objective methods quantitatively evaluate food comminution or mixing ability using standardized natural or artificial test foods. Common objective techniques include food comminution tests, two-colored gum or wax mixing tests, glucose dissolution analysis and gummy jelly-based assessments. Conclusion: Given that no single method fully captures all dimensions of masticatory function, a combined use of subjective and objective assessments is recommended to provide a comprehensive evaluation in both clinical and research settings.

Keywords: *masticatory performance, food comminution tests, two-colored gum or wax mixing tests, glucose dissolution analysis, gummy jelly-based assessments*

1. INTRODUCTION

In patients with tooth loss, masticatory function is often significantly diminished, resulting in inadequate comminution of food and a consequent reduction in the efficiency of the digestive process. Removable prosthodontic rehabilitation is considered a crucial approach to restoring the morphology and function of the masticatory system, thereby improving masticatory performance and patients' quality of life. A dental prosthesis that is properly designed and fabricated according to biomechanical and biological principles can facilitate optimal force distribution, enhance food comminution, and improve coordination among the components of the masticatory system. In contrast, poorly designed or ill-fitting prostheses may reduce masticatory performance, cause discomfort during function, and adversely affect digestive function. Therefore, the assessment of masticatory performance has increasingly been regarded as a key parameter in evaluating the functional outcomes of dental prostheses, as it directly reflects the extent of functional recovery following prosthetic treatment and plays a central role in determining the clinical value of prosthetic rehabilitation, particularly in denture therapy.

Nowadays, a variety of methods are available for the assessment of masticatory performance, using both subjective and objective methods. The selection of an appropriate assessment method depends largely on the clinical context and the specific objectives of the clinician. Accordingly, the aim of this review is to provide a comprehensive overview of the methods currently used in clinical practice to evaluate masticatory performance, thereby assisting clinicians and researchers in

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selecting the most appropriate approach for their specific diagnostic and therapeutic needs.

2. REVIEW CONTENT

2.1. Definition

According to the Glossary of Prosthodontic Terms, Tenth Edition, masticatory performance is defined as "a measure of the comminution of food attainable under standardized testing conditions", whereas chewing efficiency is defined as "the proficiency to grind or comminute a certain portion of food during a given time or across a given number of chewing strokes" [1]. The definition of masticatory performance has been considered somewhat ambiguous, as it may also encompass aspects of masticatory efficiency. According to the 2021 consensus on terminology and research methods related to masticatory efficiency, masticatory performance refers to the outcome of mastication after a specified number of chewing cycles, whereas masticatory efficiency denotes the number of chewing cycles required to achieve a predetermined masticatory outcome. In other words, masticatory performance reflects an individual's ability to comminute or fragment a test food sample after a predefined number of chewing cycles, while masticatory efficiency refers to the number of chewing cycles necessary to reduce the particle size of the test food to one-half of its original size[2].

2.2. Methods for assessing masticatory performance

2.2.1. Functional tooth units (FTUs)

Functional Tooth Units (FTUs) represent pairs of opposing posterior teeth that are in functional occlusion and contribute to the comminution of food during mastication. The concept of FTUs is widely used as an indicator of occlusal support and has been shown to correlate closely with masticatory performance. In a natural dentition, each opposing premolar pair is considered to represent one FTU, whereas each opposing molar pair corresponds to two FTUs due to their larger occlusal surface and greater role in food comminution. Consequently, a complete dentition may provide a maximum of 12 FTUs, consisting of four premolar pairs (4 FTUs) and four molar pairs (8 FTUs).

The number of functional tooth units decreases with tooth loss, particularly in the posterior region, leading to reduced occlusal support and impaired chewing ability. Previous studies have demonstrated that individuals with fewer FTUs exhibit significantly lower masticatory performance and reduced efficiency in food fragmentation. Conversely, prosthodontic rehabilitation, such as removable partial dentures, fixed prostheses, or implant-supported restorations, can restore occlusal contacts and increase the number of FTUs, thereby improving masticatory function[3].

From a clinical perspective, FTUs provide a practical index for estimating functional occlusal support in both epidemiological studies and prosthodontic treatment planning. The number of FTUs has been associated with objective measures of masticatory performance, as well as with nutritional status and oral health-related quality of life. Therefore, assessment of FTUs is often used alongside objective masticatory tests to better interpret functional outcomes in patients with tooth loss and following prosthodontic rehabilitation.

2.2.2. Subjective methods for assessing masticatory performance

Subjective methods for assessing masticatory function primarily rely on questionnaires, interviews and self-report instruments to screen for masticatory disorders and analyze an individual's perceived ability to chew food. These tools allow the collection of patient-reported outcomes, particularly perceptions of comfort or discomfort during mastication. Masticatory ability is commonly evaluated through structured interviews or oral function questionnaires, in which patients report the degree of difficulty experienced when chewing different types of food. The collected data can be quantified using various response formats, including dichotomous answers (yes/no), five-point Likert scales (ranging from "very easy to chew" to "very difficult to chew or avoided"), categorical response options (e.g., "never," "occasionally," "frequently," "always," or "slightly difficult," "moderately difficult," "very difficult," "extremely difficult"), as well as visual analog scales (VAS), with anchors ranging from "no difficulty chewing at all" to "unable to chew." Commonly used subjective assessment instruments include patient- or proxy-reported masticatory function measures, the Quality of Masticatory Function Questionnaire (QMFQ), and the Chewing Function Questionnaire (CFQ) [2]. Overall, subjective methods using questionnaires and interviews represent convenient and widely applied tools for capturing individual perceptions of chewing ability. Although

these methods do not directly measure masticatory performance, their outcomes may serve as indirect indicators of overall masticatory function. Numerous studies have demonstrated that oral health status plays a critical role and shows a close association with subjective indices, while also correlating with objective measures, underscoring the importance of subjective assessment as an integral component of comprehensive evaluations of masticatory function and oral health-related quality of life, particularly in relation to nutrition and general health.

2.2.3. Objective methods for assessing masticatory performance

Objective methods for evaluating masticatory function focus on the quantitative measurement of food comminution or fragmentation using standardized outcome measures. In clinical research, various natural foods are commonly employed as test materials, including peanuts, almonds, and raw carrots, to simulate real-life chewing conditions. In addition, artificial test materials with uniform mechanical properties and high standardizability are frequently used to enhance the reproducibility and reliability of measurements. Beyond the assessment of food comminution, several objective approaches evaluate the mixing ability of the masticatory system, most notably through the analysis of color mixing in two-colored chewing gum or wax after a predetermined number of chewing cycles. The degree of color change or homogeneity of the chewed sample is considered an indicator of masticatory coordination and functional efficiency. Furthermore, color-changeable chewing gum has been utilized to indirectly assess masticatory efficiency by quantifying color transformation associated with the extent of mixing and applied masticatory forces. Other studies assess masticatory efficiency by analyzing the breakdown of elastic test materials, such as gummy jelly, either after a fixed number of chewing cycles (representing masticatory performance) or at the point immediately before swallowing, referred to as the swallowing threshold test. Collectively, these objective methods provide specific, quantifiable indices of masticatory efficiency, offering direct and reliable evidence for the evaluation of masticatory function in clinical and prosthodontic research.

Assessment using the masticatory coefficient

The masticatory coefficient, also referred to as masticatory efficiency or biting force, is used to evaluate an individual's oral health status. This coefficient is determined by assigning a specific value to each tooth on the dental arch and summing these values to obtain the total masticatory coefficient of a dentate individual with a complete and normal dentition. Based on the number and location of missing teeth in each case, the corresponding individual masticatory coefficient can be calculated.

In adults, for ease of tooth identification and assessment, the dental arches are divided into four equal quadrants, numbered from 1 to 4 in a clockwise direction. The boundaries of these quadrants are defined by two reference axes: a horizontal axis passing through the midplane between the maxillary and mandibular arches, and a vertical axis passing through the contact point between the maxillary and mandibular central incisors.

The masticatory coefficient is an index used to evaluate an individual's oral health status. It is calculated by assigning a specific coefficient to each tooth on the dental arch, with the sum of these values representing the total masticatory capacity of an individual with complete and normal dentition, defined as 100%. Based on the number and distribution of missing teeth, the individual masticatory coefficient can be determined. For example, the loss of a maxillary first molar (tooth 6) leads to the loss of functional occlusion with its opposing mandibular first molar, resulting in an approximately 10% reduction in total masticatory capacity.

Carrot comminution test

Masticatory performance was assessed using a carrot comminution test, an objective method based on the degree of food fragmentation after mastication. Raw carrot was selected as the test food due to its hardness and brittle structure, which provide a sufficient mechanical challenge to discriminate differences in chewing ability across individuals with varying dental conditions[4]. Each participant was instructed to chew a standardized piece of carrot for a predetermined number of chewing cycles, after which the chewed bolus was collected for analysis.

The degree of comminution was evaluated by assessing the size and distribution of carrot fragments, as food particle size after mastication has been shown to correlate closely with

masticatory efficiency [5]. Smaller and more homogeneous particle sizes indicate higher masticatory performance, whereas larger fragments reflect reduced chewing efficiency. Fragmentation was assessed using a standardized scoring scale, which helps researchers examine masticatory performance of each participant.

Although the carrot comminution test is simple, inexpensive, and widely applicable, variability in carrot hardness and moisture content may influence result consistency. Nevertheless, this method remains a well-established and sensitive approach for evaluating masticatory performance, particularly in studies examining the effects of tooth loss, prosthetic rehabilitation, and aging on oral function[5].

Two-colored chewing gum mixing ability test

The two-color chewing gum mixing ability test is a widely used method for evaluating masticatory performance based on how well a test subject is able to mix two different colors of chewing gum by chewing. This method provides an objective, non-invasive, and relatively simple assessment of chewing function and has been validated in numerous dental and clinical studies[6].

In this test, a standardized piece of two-colored gum (often red and green) is chewed for a fixed number of cycles. After chewing, the chewed gum is analyzed either by visual scoring or through digital image analysis to quantify the degree of color blending. Better color mixing indicates higher masticatory performance, while less mixing suggests reduced chewing ability.

Both subjective scoring and objective digital analysis have been used. Visual assessments involve trained examiners rating the degree of color mixture against a reference scale. Digital methods use imaging software to calculate parameters such as color dispersion or mixing index, providing more precise quantitative measures of chewing performance[7].

Validity and reliability studies indicate that the test can discriminate between individuals with different masticatory abilities, including comparisons between age groups or dentition status[8]. Recent adaptations incorporate digital image analysis to objectively quantify spatial color mixing, improving accuracy and reducing examiner bias. These approaches have been applied not only to dental research but also to broader clinical settings where chewing function is important.

Two-colored wax mixing ability test

Masticatory performance was assessed using a two-colored wax mixing ability test, which evaluates the capacity to mix and homogenize a bolus during mastication. This test focuses on bolus manipulation and kneading ability rather than food comminution, thereby reflecting a complementary aspect of masticatory function [5]. A standardized bolus composed of two differently colored paraffin waxes was used, and participants were instructed to chew the bolus for a predetermined number of chewing cycles. After chewing, the wax specimen was flattened, and the degree of color mixing was evaluated using a visual reference scale. The extent of color homogeneity reflects masticatory mixing ability, with greater uniformity indicating better masticatory performance[9].

Because wax is soft, cohesive, and does not fragment during chewing, the test is particularly suitable for elderly individuals and patients with reduced occlusal support. However, some participants, especially older adults may experience discomfort when chewing wax, which should be considered when selecting this method for clinical or epidemiological studies[5, 9].

Glucose dissolution test using Glucosensor© (GC, Japan):

Objective masticatory performance was evaluated by quantifying the amount of glucose extracted from a standardized gummy jelly following a prescribed chewing protocol. Participants were instructed to chew the gummy jelly for a defined number of cycles and then expectorate the chewed specimen, after which the filtrate was collected and glucose concentration measured using a Glucosensor© device (GC, Japan) as a quantitative indicator of masticatory performance. Previous studies have demonstrated a strong positive correlation between glucose concentration and surface area of comminuted gummy jelly particles, supporting the validity and accuracy of glucose extraction as a measure of mastication[10].

The amount of glucose extracted has also been shown to correlate with functional measures of masticatory movement, suggesting that higher glucose release reflects more effective mastication (e.g., stable rhythmic movements with greater

mandibular displacement)[11].

Although this method requires specialized equipment and strict standardization of test food preparation and rinsing/dissolution procedures, it offers a quantitative and reproducible measure that is sensitive to variations in chewing performance and correlates with broader measures of masticatory function and oral health.

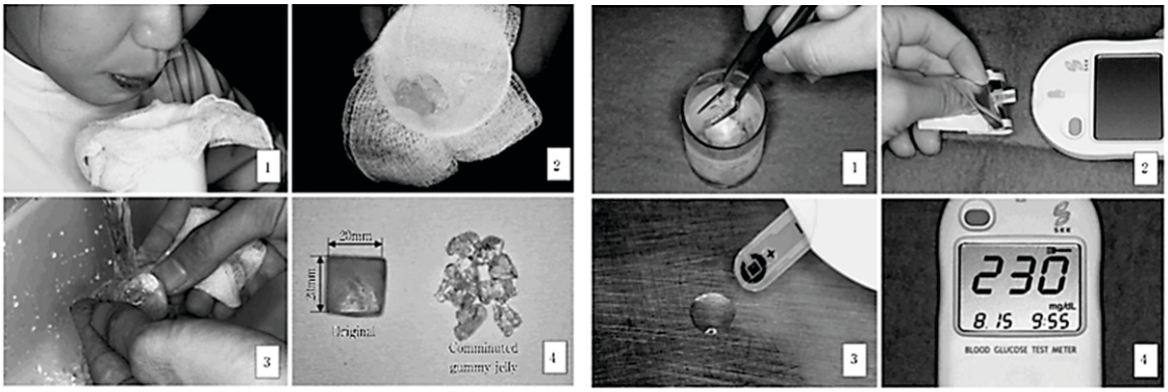

Figure 1. Procedure for measuring dissolved glucose using a Glucosensor [12]

Assessment of masticatory performance using gummy jelly (UHA Mikakuto, Osaka, Japan)

Masticatory performance was assessed using a standardized gummy jelly test food (UHA Mikakuto, Osaka, Japan), which has been widely adopted in clinical and epidemiological research as an objective measure of chewing function. The gummy jelly is a specially formulated elastic test material with controlled hardness and consistency, facilitating reproducible mastication and glucose extraction for quantitative analysis.

Each gummy jelly specimen was standardized in size (10 × 10 × 10 mm) and weight (2 g), and the glucose released upon comminution reflects the degree of masticatory performance. Participants were instructed to clean the oral cavity by tooth brushing and then seated upright with the Frankfort horizontal plane parallel to the floor. One piece of gummy jelly was chewed naturally for 20 cycles without swallowing, after which the chewed specimen was expectorated onto gauze placed over a paper cup.

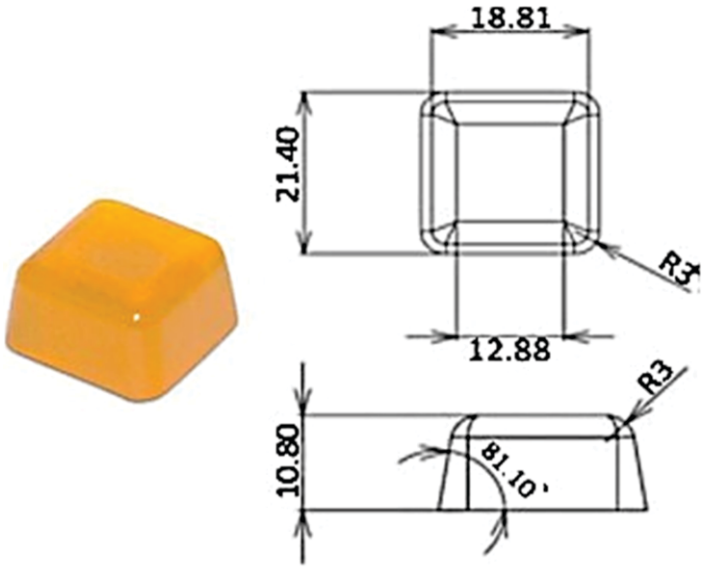

Figure 2. Shape and dimension of gummy jelly [12]

Masticatory performance was evaluated using two complementary approaches. For the comminution-based assessment, the degree of fragmentation of the chewed gummy jelly was visually compared with a standardized reference scale, which has been shown to correlate with glucose-based measures of mastication [13]. For quantitative assessment, the chewed specimen was rinsed with distilled water for 30 seconds to remove residual saliva and surface glucose, then

immersed in 15 mL of distilled water and gently agitated. The glucose concentration of the resulting solution was measured using a glucose meter (e.g., Glutest, Sanwa Chemical Laboratory, Nagoya, Japan) as an indicator of masticatory function. Previous studies have demonstrated a strong correlation between the glucose concentration dissolved from comminuted jelly particles and objective masticatory performance, and established reference values for healthy adults at approximately 150 mg/dL [14]. Reduced masticatory performance was defined as a glucose concentration below this reference value or a comminution score of less than 2 points on the visual scale. This combined method provides objective and reproducible data for the evaluation and comparison of masticatory performance in clinical and community-based studies.

3. CONCLUSION

This review provides a comprehensive synthesis of current methods for assessing masticatory performance, encompassing both subjective and objective approaches. The findings highlight that masticatory performance is a complex and multidimensional function involving food comminution, bolus mixing, and patient perception, and therefore cannot be adequately evaluated using a single method. Subjective assessments offer valuable insights into perceived chewing ability and oral health-related quality of life, whereas objective methods, such as comminution-based tests, mixing ability tests, and particularly gummy jelly-based assessments combined with glucose dissolution analysis, provide reliable and quantitative measures of functional performance.

The main contribution of this review lies in its systematic integration of these diverse assessment methods into a unified and clinically relevant framework. By clarifying the strengths and limitations of each approach, this study emphasizes the complementary roles of subjective and objective evaluations and supports the use of a combined assessment strategy to achieve a more comprehensive and accurate evaluation of masticatory function. Given that no single method fully captures all dimensions of masticatory function, the combined use of subjective and objective assessments is strongly recommended to ensure a comprehensive evaluation in both clinical and research settings. Furthermore, this review identifies current gaps in standardization and highlights the need for methodological consistency and the incorporation of advanced technologies in future research.

Overall, this work contributes to both clinical practice and research by providing a structured basis for selecting appropriate assessment methods and improving the evaluation of functional outcomes in prosthodontic rehabilitation, thereby supporting more effective and patient-centered care.

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Đánh giá hiệu suất nhai: Các phương pháp và ứng dụng lâm sàng

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TÓM TẮT

Đặt vấn đề: Hiệu quả nhai là một chỉ số quan trọng phản ánh chức năng miệng và mức độ thành công của phục hình răng, đặc biệt ở những bệnh nhân bị mất răng. Suy giảm chức năng nhai có thể làm giảm khả năng nghiền nhỏ thức ăn, từ đó ảnh hưởng bất lợi đến quá trình tiêu hóa và chất lượng cuộc sống. Các phục hình răng được thiết kế phù hợp có khả năng phục hồi hiệu quả nhai thông qua việc tối ưu hóa sự phân bố lực nhai, tăng cường khả năng phân mảnh thức ăn và cải thiện sự phối hợp của hệ thống nhai; ngược lại, các phục hình không phù hợp có thể làm suy giảm chức năng và gây khó chịu cho bệnh nhân. Do đó, đánh giá hiệu quả nhai đã trở thành một thông số thiết yếu trong việc xác định mức độ hồi phục chức năng sau điều trị phục hình. Nội dung tổng quan: Hiệu quả nhai được định nghĩa là mức độ nghiền nhỏ thức ăn đạt được trong những điều kiện tiêu chuẩn hóa, khác với hiệu suất nhai - khái niệm dùng để chỉ số chu kỳ nhai cần thiết để đạt được một kết quả nhai xác định. Các phương pháp đánh giá hiện nay bao gồm cả cách tiếp cận chủ quan và khách quan. Các phương pháp chủ quan chủ yếu dựa trên bảng câu hỏi và tự đánh giá của bệnh nhân nhằm ghi nhận khả năng nhai theo cảm nhận cá nhân. Trong khi đó, các phương pháp khách quan đánh giá định lượng khả năng nghiền nhỏ hoặc trộn đều thức ăn bằng cách sử dụng các loại thực phẩm thử nghiệm tự nhiên hoặc nhân tạo được chuẩn hóa. Những kỹ thuật khách quan thường được áp dụng bao gồm thử nghiệm nghiền nhỏ thức ăn, thử nghiệm trộn kẹo cao su hoặc sáp hai màu, phân tích sự hòa tan glucose và đánh giá dựa trên kẹo dẻo (gummy jelly). Mỗi phương pháp phản ánh những khía cạnh khác nhau của chức năng nhai và có sự khác biệt về mức độ phức tạp, khả năng tái lập cũng như tính ứng dụng lâm sàng. Kết luận: Do không có phương pháp đơn lẻ nào có thể phản ánh đầy đủ mọi chiều cạnh của

chức năng nhai, việc kết hợp các đánh giá chủ quan và khách quan được khuyến nghị nhằm cung cấp một cái nhìn toàn diện trong cả thực hành lâm sàng và nghiên cứu khoa học.

Từ khoá: *hiệu suất nhai, hiệu quả nhai, phục hình, chu kì nhai, thử nghiệm nghiền nát thức ăn, thử nghiệm trộn màu, phân tích độ hoà tan glucose, phương pháp đánh giá sử dụng kẹo dẻo*

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