ACTA SCIENTIFIC DENTAL SCIENCES

Volume 9 Issue 5 May 2025

Research Article

Clinical Evaluation of Masticatory Efficiency in Edentulous Patients Using a Two-Color Chewing Gum Test

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Received: April 21, 2025

Published: April 29, 2025

Abstract

Background: Edentulism is a condition that is more prevalent in the aging population and it results from both oral pathological factors and the systemic aging process. Masticatory efficiency refers to the ability to triturate food effectively into smaller parts and is a key indicator of oral function. There are several methods for assessing masticatory function and neuromuscular coordination including gnathodynamometers, electromyography and measurements of mandibular range of motion. However, the chewing gum test remains one of the most accessible methods. The goal of this study was to objectively evaluate the difference in masticatory efficiency between two groups: dentate individuals and completely edentulous patients treated with conventional dentures.

Methods: In this study the two-color chewing gum method was used with chewing-gum specimens analyzed both subjectively by two examinators and objectively by measuring images captured with a smartphone camera via dedicated software.

Results: The study revealed significant differences between the two groups in both objective measurements and subjective scores. The Intraclass Correlation Coefficient (ICC) was 0.913 indicating excellent agreement between the two evaluators. The small p-value (p = 4.15e-09) suggests that the observed ICC is statistically significant, meaning that the agreement between the examiners is unlikely to be due to chance. Both assessment methods successfully distinguished between the two groups, though the subjective evaluation method demonstrated superior discriminative capacity. There are still several elderly patients who maintain a relatively good masticatory efficiency possibly due to well-adapted dentures.

Conclusion: This study is consistent with the challenges faced by edentulous patients in terms of chewing function, as prosthetic devices may not restore the masticatory function of natural teeth. The chewing gum test proved to be a reliable, non-invasive, and practical method for assessing and monitoring masticatory function in complete denture wearers, with value in both clinical and research settings. Among the assessment tools, the subjective method showed greater sensitivity in distinguishing between dentate and edentulous individuals.

Keywords: Two-Color Chewing Gum Test; Masticatory Efficiency; Edentulism; Dental Diagnostic

Introduction

The aging phenomenon is a progressive and irreversible biological process that results in the deterioration of cells and organs after their stage of maturation, as a consequence of the appearance of a number of processes including: genomic instability, epigenetic alteration, mitochondrial dysfunction and altered intracellular communication [1]. Frailty syndrome is described as a condition related to the aging process leading to a significant decline in body functions. This condition makes individuals more susceptible to disease. It encompasses a range of symptoms such as physical weakness, exhaustion, complex health problems and a reduced

ability to withstand various medical procedures [2]. Specific to the stomatognathic system, frailty syndrome is defined as a decline in oral function in older people that includes problems such as reduced masticatory ability, difficulty swallowing, poor oral motor skills and reduced tongue strength. One of the skeletal muscle disorders with relevance to masticatory dysfunction is sarcopenia, which is characterized by progressive and generalized loss of skeletal muscle mass, accompanied by decreased muscle strength and/or physical performance [3]. Thus, the masticatory function of sarcopenic patients is impaired and the consequences are less nutritious food choices, such as soft foods that require shorter chewing time, have low fiber content and lower nutritional values. A diet that lacks protein and does not provide enough energy to the body can lead to sarcopenia, thus creating a vicious circle between sarcopenia and malnutrition.

Masticatory efficiency refers to an individual's ability to triturate food into small pieces until a consistency that will favor swallowing and subsequent digestion is achieved. Masticatory efficiency is an objective parameter and is related to the number of cycles required to reach the optimal food particle size [4]. Kosaka., *et al*. showed that bite force, number of teeth included in masticatory units, periodontal status and gender influence masticatory efficiency [5]. The reduction in masticatory efficiency is primarily attributed to insufficient occlusal support [6] identifies the primary contributor, including the selection of soft foods and insufficient vitamin consumption [7]. Musculoskeletal fragility [8] and cognitive decline significantly contributes to the reduction of masticatory efficiency [9]. The maximal masticatory forces in complete denture wearers are 5-6 times lower than those in individuals with intact dentition; these forces are predominantly supported by the alveolar mucosa and by the edentulous ridges, leading to bone resorption over time [10]. Reduced masticatory efficiency the direct consequence of edentulism. Totally edentulous individuals have difficulty chewing food, and over time develop a preference for soft foods, which have low nutritional values. As a result, they tend to favor diets higher in carbohydrates. Decreased nutrient intake will lead over time to exacerbation of oral and general fragility.

There is a large variety of diagnostic techniques that have been developed to assess the neuromuscular coordination and masticatory function. The examination of the swallowing thresholds evaluates the masticatory efficiency by measuring the size of the test food after a specific number of chewing cycles [11]. To assess the strength of the masticatory muscles, gnathodynamometers can be utilized to measure the maximum bite force [12], while electromyography (EMG) of the masseter muscles helps track the electrical activity during chewing, allowing to detect any signs of muscle fatigue or imbalance [13]. The evaluation of mandibular range of motion (including maximum mouth opening, protrusive, and lateral movements) is important for assessing neuromuscular dysfunction. Restricted jaw movements can directly affect masticatory efficiency, muscle fatigue and the ability to chew effectively [14]. In both clinical practice and scientific research, the chewing gum test remains one of the most widely utilized methods for assessing masticatory efficiency. This technique involves participants chewing a standardized piece of gum for a predetermined period, allowing for the evaluation of various parameters such as chewing efficiency, bite force, and masticatory endurance. By measuring key aspects of the chewing process, such as the duration, frequency, and force of chewing cycles, clinicians can assess masticatory performance in a manner that closely mirrors the patient's actual experience of mastication. The chewing gum test has been incorporated into numerous studies investigating masticatory dysfunction across various populations, including edentulous patients, individuals with prosthetic devices, and those with temporomandibular disorders [15,16]. The two-color chewing gum test is a specific modification of the conventional chewing gum test whereby masticatory function is evaluated using two different colored chewing gum as markers. This method was first introduced by van der Bilt in the early 2000s [17] and uses the color change as a visual cue to monitor several aspects of the chewing process, therefore allowing a more thorough and impartial assessment of a person's chewing efficiency. Van der Bilt developed this method as a more refined approach to assessing masticatory performance, by analyzing the development of color transformation during mastication, therefore providing a complete assessment of several criteria, including chew force and consistency.

Edentulism is a condition that is more prevalent in the aging population and is a consequence of oral pathologic factors as well as a consequence of the systemic aging process. Total dentures are the standard treatment of total edentulism and the difficulties in their realization can be challenging for the clinician: severe bone atrophy, presence of unsupported mucosa, insertion of the genioglossus muscle at the level of the lower alveolar ridge, herniation of the buccal floor on the edentulous ridge or the existence of areas of thin and friable mucosa. In these situations, it may be possible to increase retention by making lingual flanges [18]. or to anchor

the prosthesis with two mandibular implants [19] in some cases, even a single implant can bring significant improvements. Some patients prefer fixed dentures because of their high stability, but others opt for removable dentures because of limited financial possibilities and ease of cleaning [20].

Material and Methods

The study was conducted at the Faculty of Dentistry of the Carol Davila University of Medicine and Pharmacy of Bucharest, Romania. It was based on 2 groups of patients (dentate and edentulous patients with conventional total dentures obtained analogically) whose masticatory efficiency was measured using the 2-color chewing gum test, the evaluation of the results being performed after photographing the samples with the digital camera of a mobile phone, by two methods: subjective and objective (electronic).

It was based on 2 groups: control group and experimental group. The control group was composed of volunteer students of the Faculty of Dentistry of the University of medicine anf Pharmacy "Carol Davila" Bucharest, Romania, from the 5th and 6th years of study, with intact dentition, with no dental pathology, with no occlusal dysfunction and without diagnosed temporomandibular disorders. The experimental group consisted of totally edentulous patients with conventional total dentures, no temporomandibular dysfunction, no pain in the oro-facial region and no neuromuscular involvement. The prostheses were made by the analog method by a prosthodontic specialist, clinically and technically evaluated and found to meet the functional criteria.

The two-color chewing gum technique was used to evaluate chewing efficiency. Each test specimen was formed by chewing gum from Trident Chewing Gum (Mondelēz International), and consisted of ½ Trident Pineapple Twist chewing gum, yellow in color and ½ Trident Tropical Twist chewing gum, orange in color. The two halves were moistened with water and superimposed without deformation, resulting in a specimen 4 mm thick, 22 mm long. Trident chewing gum meets some of the ideal specimen criteria designed by Schimmel., *et al*. [21]. the specimen does not contain any white tints, the colors are visible on unchewed specimens, the gum does not stick to the denture material, are not too bulky, too hard, but relatively easy to chew, samples can be kept for later analysis, colors are stable over time, the taste is pleasant for most people, gums do not contain sugar, samples can be individually packaged to meet hygienic conditions and to improve handling.

Participants were instructed to chew the specimens for 20 chewing cycles.

After 20 masticatory cycles, samples were collected from the oral cavity, excess saliva was removed and placed in transparent plastic bags 60 mm wide, 80 mm high, 50-micron foil, zip lock sealed. Each sample was then pressed between two glass plates until specimen thicknesses of approximately 1 mm were obtained.

Each sample was photographed using a Motorola Edge 30 fusion (2022) cell phone with the following rear camera features [22] main camera 50 MP (wide), f/1.8 aperture, 1.0 µm pixels, multidirectional autofocus with phase detection and optical image stabilization, 13 MP (ultrawide) secondary camera with f/2.2 aperture, 120-degree field of view, 1.12 µm pixels and autofocus, 2 MP depth camera with f/2.4 aperture. The photos were taken using a tripod to fix the mobile phone to a stable point, from a distance of 20 cm, in ambient light, using a white background, using auto shooting mode, without customized settings.

Subjective assessment

Prior to pressing the specimens to the desired thickness, each specimen was given a score from 1 to 5 by two operators after visual assessment as follows:

- 1 = Non-homogenized chewing gum, with impressions of cusps or simple bending of the sample
- 2 = Large inhomogeneous portions
- 3 = Slightly homogenized bolus, but with well demarcated orange or yellow portions
- 4 = Well homogenized bolus but uneven in colour
- 5 = Perfectly homogenized bolus, uniform color

For example, the specimen in figure 1. will score 1, as it is unhomogenized, the two chewing gums being simply joined and pressed into a single food bolus.

Electronic evaluation

After the photos were taken, they were transferred to the internal memory of a computer with the following technical specifications: processor Intel(R) Core(TM) i5-7200U CPU @ 2.50GHz 2.70 GHz, Installed RAM: 4.00 GB, System type: 64-bit operating system, x64-based processor, Windows 10 Home.

Each photo was entered into the ViewGum software [23], available free for download. ViewGum analyzes the color distribution in chewed gum samples by calculating the circular standard deviation of the hue component (Figure 2). A lower standard deviation indicates better mixing and, consequently, higher masticatory efficiency.

By moving the mouse cursor and clicking around the surface of the chewing gum, we selected the area to be analyzed. Then we marked the background of the image with a red broken line, in addition to the previous commands by pressing the "SHIFT" key. After

Figure 1: Food bolus produced by a totally edentulous, conventionally bimaxillary prosthetized patient.

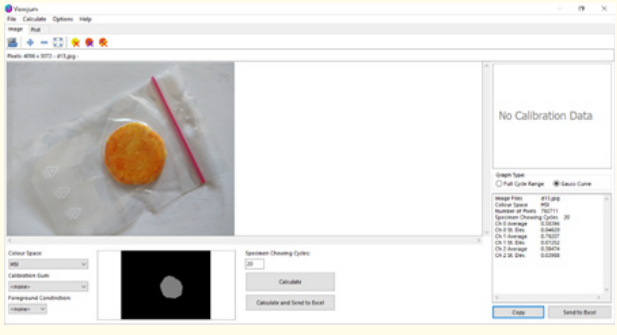

Figure 2: Screenshot, ViewGum software.

marking the two areas, we pressed the 'CALCULATE' button and obtained the data needed for the evaluation.

For statistical analysis of the data, R version 4.4.0 (24-04-2024) and RStudio version 2023.03 were used. R is an open-source programming language and a specially designed environment for statistical computing and graphics. Complementary to R, RStudio functioned as an integrated development environment (IDE) that significantly increased productivity. Version 2023.03 of RStudio provided a user-friendly interface, advanced coding capabilities, and seamless integration with R, thus simplifying the processes of scripting, debugging, and visualization of statistical analyses. The combination of R and RStudio enabled complex data analysis and the generation of high-quality visualizations essential for the rigor and clarity of the proposed study.

Results

The study group comprised 20 participants, 14 females and 6 males. The minimum age of the participants was 24 years and the maximum age was 82 years, with a mean value of 41 years. The minimum age of the women ranged from 24 to 74 years, with a median of 24 and a mean of 35.5 years, indicating that the vast majority of the patients were young. The minimum age of men ranged from 24 to 82 years, with a median of 65.5 and a mean of 56 years, showing that the vast majority of male patients were elderly.

Women	Minimum value	First quartile	Median	Mean	Third quartile	Maximum value
	24	24	24	35.5	46.5	74
Men	Minimum value	First quartile	Median	Mean	Third quartile	Maximum value
	24	34	65.5	56	67.5	82

Table 1: Age and gender distribution of all participants.

The group of edentulous patients comprised 4 female and 4 male patients, aged between 54 and 82 years. This group represents 40% of the study group. The reference group of young patients comprises 10 female and 2 male patients, all aged 24 years. The reference group represents 60% of the study group.

In this study, central tendency indicators were calculated using data collected by the two assessment methods. The minimum and maximum values were equal for both subjective assessments, as well as the medians, and the mean values were 3.2 for the first assessment and 3.25 for the second objective assessment. The first and third quartiles (Q1, Q3) also have equal values. The interquartile range (IQR), which shows the spread of the data of the middle portion of the set is equal to 2. For the objective evaluations, the reference parameter was the standard deviation of hue (h_sd). Its minimum value in the whole data set was 0.04110 and its maximum value was 0.10228. The mean value was 0.06962, median 0.06527, first quartile (Q1) 0.05062, third quartile 0.09170(Q3), and interquartile range 0.04108 (IQR).

Skewness and kurtosis were applied to describe the shape of the data distribution in the study group. Skewness measures the asymmetry of the data distribution. A skewness value close to zero indicates a symmetric distribution. Positive skewness indicates a distribution with a tail extended to the right, while negative skewness indicates a tail extended to the left. Kurtosis calculates the coefficient of kurtosis. If the value is less than 3, we have a flat series, i.e. the values are spread out and appear to have similar probabilities of occurrence, if the value is 3, we have a normal series, and if the value is greater than 3, we have a high series, i.e. the values are more concentrated around the mean.

Thus, for the subjective evaluations, skewness has a negative value, with high values predominating in the series with low extreme values. This suggests that the majority of patients have higher masticatory efficiency scores, with a smaller number of patients showing lower efficiency. Kurtosis has a value less than 3, resulting that the data series is flat, and the values are spread out and appear to have similar probabilities of occurrence. The flatter peak and lighter tails suggest that the distribution of masticatory efficiency scores is more spread out and less sharp than a normal distribution. There are fewer extreme values (both high and low values) and scores are more evenly distributed around the mean. This implies that, while there is variation in masticatory efficiency,

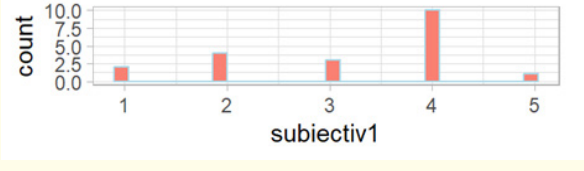

Figure 3: Data distribution for the first subjective assessment of all participants.

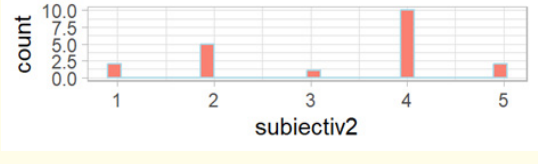

Figure 4: Data distribution for the second subjective evaluation of all participants.

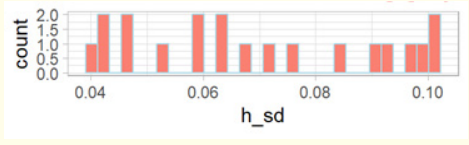

Figure 5: Data distribution for the objective assessment of all participants.

extreme values (very high or very low) are less frequent. Most patients have masticatory efficiency scores that are relatively close to each other, with no sharp peaks in the distribution. By applying skewness to the data obtained by objective assessment, a positive value was obtained, so small values predominate and the series seems to have high extreme values. Kurtosis has also this time a value less than 3.

Subjective assessment

Overall, score 4 predominates, describing a well homogenized but unevenly colored bolus. Only some of the participants obtained identical scores on the two subjective assessments.

To quantify the proportion of the total measurement variability that can be attributed to differences between subjects, as opposed to variability due to measurement error or differences between examiners, the intraclass correlation coefficient was calculated. The Intraclass Correlation Coefficient (ICC) is a statistical measure used to assess the reliability or degree of agreement between different examiners or measurements of the same subject. ICC values range from 0 to 1, with higher values indicating higher reliability and agreement. In the present study, it has a value of 0.913, indicating an almost perfect agreement between the two examiners. The small p-value (p = 4.15e-09) suggests that the observed ICC is statistically significant, meaning that the agreement between the examiners is unlikely to be due to chance. The narrow 95% confidence interval (0.795 to 0.965) further supports the precision of the ICC estimate.

The group of dentate patients has a mean score of 4. Only two patients with integral dentition obtained the maximum score equal to 5, which describes a perfectly homogenized bolus of uniform color. Skewness has negative values for both subjective ratings for patients with integral dentition, indicating that the distribution

has a longer tail on the left side. The majority of masticatory efficiency scores are clustered towards higher values, with fewer cases of lower scores. This suggests that the majority of patients in the group have high masticatory efficiency, but there are also a few patients with significantly lower efficiency. Kurtosis has values greater than 3 for both subjective ratings, suggesting that the distribution has heavier tails and a sharper peak compared to a normal distribution. This implies that there are more extreme values (both large and small) in the distribution, and the scores are more clustered around the mean with a high peak. Most of the masticatory efficiency scores are high, but there is a significant presence of extreme values with low efficiency, resulting in a long left tail. The distribution has a sharp peak, indicating that many patients have near average efficiency scores, but there are pronounced extreme values. This distribution might reflect the generally high masticatory efficiency expected in young patients with intact dentition. The presence of lower extreme values could be due to specific problems such as orthodontic problems, temporary dental problems or other health conditions affecting masticatory efficiency.

The group of totally edentulous patients shows a mean score of 2, which describes the presence of large inhomogeneous portions on the surface of the formed bolus. No edentulous patient obtained a maximum score. Skewness is positive for the subjective method in edentulous patients, and this value indicates a slight positive asymmetry. The distribution has a longer tail on the right-hand side, which means that there are more cases of higher masticatory efficiency scores, but a few patients have notably lower scores. Most of the scores are clustered at the lower end of the scale, with a tail extending to higher values. The kurtosis value for the subjective edentulous ratings is slightly less than 3, suggesting that the distribution is somewhat flatter than a normal distribution. This indicates fewer extreme values (both large and small) and a broader peak. The distribution is not very sharp and the data are more evenly spread around the mean compared to a normal distribution. In edentulous patients, this distribution reflects a general decrease in masticatory efficiency. However, there are still a number of elderly patients who maintain a relatively good masticatory efficiency, possibly due to total dentures.

The Welch's t-test, also known as the unequal variances t-test, is a version of the two-sample t-test that does not assume that the two groups have equal variances. This test is used to determine whether the means of two populations are significantly different, especially when the samples have different variances and/or different sizes. If the p-value associated with the t-statistic is less than a predefined significance level (usually 0.05), then the null hypothesis is rejected, indicating that there is a statistically significant difference between the means of the two populations. By applying the Welch's t-test for two independent samples, in both cases, the p-values are significantly less than the standard significance level of 0.05, indicating that there are significant differences between the means of the intact and edentulous groups for the subjective1 and subjective2 variables. This means that there is sufficient evidence to reject the null hypothesis that there are no differences between the groups in these subjective variables. Thus, it can be concluded that for both the first subjective and the second subjective assessments, there is strong statistical evidence that the means of the two study groups are significantly different.

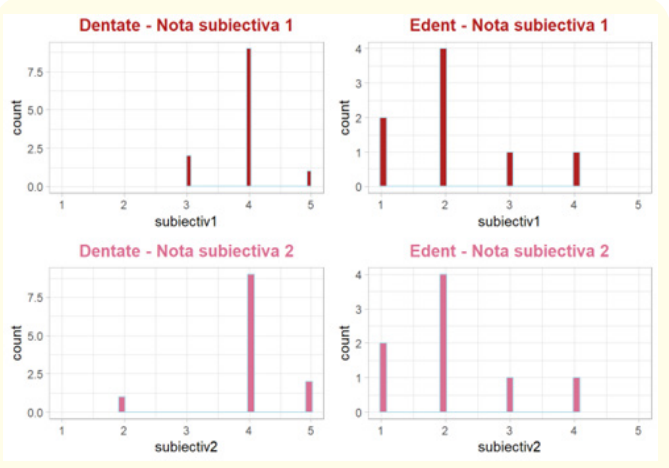

Figure 6: Comparison between the subjective evaluations of the two groups

Objective assessment

The dataset that was analyzed comprises 10 potential numerical variables to be analyzed: the number of pixels of the uploaded pictures: mean and standard deviation for hue (hereafter denoted *as Hue-h*), mean and standard deviation for saturation (hereafter denoted *as Saturation-s*), mean and standard deviation for brightness (hereafter denoted *as Brightness-b*), patients' age, and two subjective ratings given by the analyst.

In the objective evaluation, the standard deviation of the hue variability (hereafter denoted *as h_sd*) was analyzed in particular. The standard deviation of the parameter provides a measure of the

spread or dispersion of the hue values around the mean hue value. It shows how much the individual hue measurements deviate from the mean hue value. A larger standard deviation suggests a higher variability of hue in chewing gum samples, i.e. a lower chewing efficiency, while a smaller standard deviation indicates a higher consistency of hue, i.e. a more homogeneous chewing bolus.

The hypothesis to be tested next is whether there are significant differences between the two groups of patients (the reference group of patients with intact dentition, hereafter referred to as *dentate*, and the group of edentulous patients, hereafter referred to as *edentulous*) in the measured values as well as in the subjective ratings. From Figure 8, on closer examination, it can be seen that there do indeed appear to be differences between the values of the two groups. For example, the Saturation Mean is more concentrated for the reference group, whereas the Saturation Mean has values over a wider range for the edentulous group. The same can be observed for Britghtness Mean. The plots for the standard deviation of hue (h_sd.), although appearing to have similar values for the two groups, have opposite shapes, however, indicating that the reference group is dominated by low values and the edentulous group by high values for this measure. This is particularly important because it supports the initial hypothesis that there are significant differences between the two groups, which can be easily seen from figure 7.

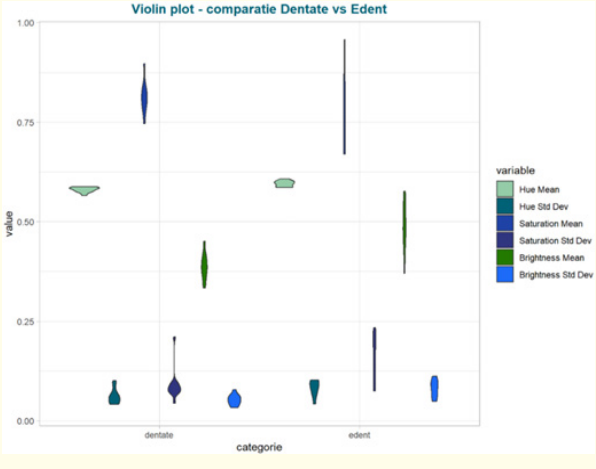

Figure 7: Comparison of objective values between the two groups.

Integrating also the numerical analysis, in table 2 can be seen the values for mean, median, coefficient of asymmetry and coefficient of flattening for the numerical values describing the objective characteristics analyzed. When strictly analyzing the value of h_sd, it can be seen that for the group of patients with integral dentition, the minimum value of h_sd was 0.0411 and the maximum value was 0.10074. Mean value was 0.06163, median 0.05900, Q1 = 0.04628, and Q3 = 0.06636.

Applying skewness for this group, it was observed that most of the data points are concentrated at the lower end of the scale, with a tail extending towards higher values. This suggests that there are more instances of lower values and fewer instances of higher values, but there is a significant presence of extreme values or higher scores. In the kurtosis case, it was observed that the peak of the distribution is neither too narrow nor too flat, but has a moderate peak. There is a balanced distribution of data points around the mean, with no excess of extreme values or lack of extreme values compared to a normal distribution.

For the group of totally edentulous patients, the values obtained by objective evaluation for h_sd were: minimum value 0.04163, maximum value=0.10228, mean= 0.08161, median=0.08758, Q1= 0.06983, Q3= 0.09763. The negative skewness value indicates that most observations have less variability in hue variation, suggesting more consistent or similar measures of hue variation in our samples. Kurtosis indicates a typical distribution with a moderate peak, reflecting variability in hue variance values without extreme concentrations around the mean.

Applying the Welch's t-test for the parameter h_sd, a p-value of less than 0.05 was obtained, which indicates that there are significant differences between the means of the groups of patients with integral and edentulous dentition for the variable h_sd and we can reject the null hypothesis. However, the p value = 0.04667, so the differences between the two groups are small.

The T-test applied for the values of the other image parameters recorded by the ViewGum software revealed p values less than 0.05, showing that overall there are differences between the groups evaluated by the objective method.

Dentate	Hue Mean	Hue Std Dev	Saturation Mean	Saturation Std Dev	Brightness Mean	Brightness Std Dev	Age
	Mean 0.5807 Median 0.5825 Skew-ness0.968 Kurtosis 3.097	Mean 0.06163 Median 0.059 Skewness0.883 Kurtosis 2.695	Mean 0.8119 Median 0.8082 Skewnes0.501 Kurtosis 3.486	Mean 0.08916 Median 0.08027 Skewness 2.366 Kurtosis 8.037	Mean 0.3859 Median 0.3825 Skewness 0.226 Kurtosis 2.695	Mean 0.05242 Median 0.05098 Skewness 0.288 Kurtosis 2.455	Mean 24 Median 24 Skewness- Kurtosis -
Edentu-lous	Hue Mean	Hue Std Dev	Saturation Mean	Saturation Std Dev	Brightness Mean	Brightness Std Dev	Age
	Mean: 0.595 Median 0.5969 Skewness 0.043 Kurtosis 1.706	Mean: 0.08161 Median: 0.08758 Skewness -0.858 Kurtosis 2.639	Mean: 0.7887 Median: 0.766 Skewness0.483 Kurtosis 2.111	Mean: 0.15798 Median: 0.17007 Skewness -0.154 Kurtosiss 1.364	Mean: 0.4877 Median: 0.4841 Skewness -0.154 Kurtosis 2.343	Mean: 0.08087 Median: 0.08424 Skewness -0.119 Kurtosis 1.773	Mean: 67.25 Median: 66.5 Skewness 0.284 Kurtosis 2.89

Table 2: Descriptive statistics for objective numerical values in the data set.

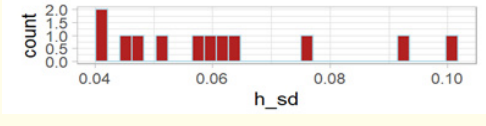

Figure 8: Distribution of the objective data of the group of patients with integral dentition.

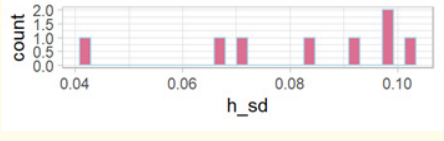

Figure 9: Distribution of objective data of the group of totally edentulous patients.

Discussions

In this study, the patient group consisted of dentate patients and edentulous patients who formed two contrasting groups in terms of age and masticatory efficiency. Although the group consisting of dentate patients has a small number of participants, by age, oral and general status and socioeconomic status, they may represent "ideal masticators". Given the lack of variability in the age of the patients, as well as the unequal gender distribution in the reference group, a good representation of the possible states of masticatory performance in the sample cannot be expected. The group of edentulous patients comprised evenly distributed gender participants, covering a wide age range. In their case, the estimates could be representative of a larger population, but due to the small number of people included in the study, there is a risk of Type II statistical errors. Statistical analysis of the data of the entire group of patients obtained by subjective assessment showed that the majority of patients had

high masticatory efficiency scores, with a smaller number of patients showing lower efficiency. These results were influenced by the disproportionality between study groups, with patients with integral dentition representing 60% of the group. When applied to each group individually, statistical methods showed that there was strong evidence that the means of the two study groups were significantly different. When assessed objectively, the data for the whole study group show that small values with large extreme values predominate, which is also influenced by the disproportionality between the study groups. The results of our study are similar to the results of Sato., *et al*. (Sato, Ohtsuka, and Ueno) who compared chewing time, chewing cycles, and chewing force in 2 groups of patients (dentate and edentulous). Individuals with natural teeth demonstrated significantly higher masticatory efficiency, which was expected as natural teeth facilitate more efficient chewing. In contrast, edentulous individuals, even when using prosthetic devices such as dentures, showed a notable reduction in masticatory efficiency. These individuals required longer chewing times, engaged in multiple chewing cycles and exhibited weaker chewing forces. Edentulous individuals often experience difficulty chewing gum due to reduced retention and stability of full dentures, particularly in the lower jaw. Notably a 2017 study by Kaya and colleagues examined the validity and reliability of this method, particularly in children with mixed dentition. Their findings provided evidence supporting the efficacy and reliability of this method in assessing masticatory efficiency in the pediatric population [24].

Our results align with other research demonstrating that tooth loss is a risk factor for oral dysfunction in the general population [25]. In a study conducted by Miura., *et al*. (2003), the relationship between masticatory function and quality of life was thoroughly examined in a cohort of 200 elderly adults. The authors highlighted that reduced masticatory ability, influenced by factors such as tooth loss and denture use, significantly impacts various aspects of daily life-including nutritional intake, social engagement, and psychological health [26]. The study of Levreault., *et al*. revealed that during maximal clenching, in individuals with complete dentition, exhibited a highly coordinated pattern of electromyographic activity in both the masseter and temporalis muscles. In contrast, edentulous individuals displayed a different muscular pattern. While the temporalis muscle exhibited minimal activity relative to the dentate group, there was a notable compensatory increase in the activity of the masseter muscle to produce the clenching force. This suggests that, in the absence of teeth, individuals predominantly rely on the remaining functional muscle - the masseter - to generate the necessary force for clenching [27].

One of the first studies to use different colored chewing gums is that of Liedberg and Owal, the authors relying strictly on visual analysis of the samples and assigning scores for both the degree of mixing and the shape of the resulting specimens at the end of the chewing cycles [28]. Van der Bilt., *et al*. (2010) used two tests to assess masticatory performance, one of comminution of a synthetic material and one of mixing chewing gums of different colors [29]. They highlighted that the chewing gum test is not suitable for young patients with intact dentition, as they are able to homogenize the food bolus after 20 masticatory cycles. The comminution test has proven to be more useful in young patients. On the other hand, for elderly patients, significant correlations were observed between the comminution test and the gum mixing test. The authors concluded that measuring the degree of gum mixing is a good method to determine masticatory function in subjects with limited masticatory performance. The addition of a comminution test to the present study would have helped to assess an additional component of masticatory function and would have led to more robust results with a more detailed description of total edentulous masticatory function but would have made the study more difficult to conduct and would not have served the purpose of simplifying the assessment method as much as possible. A disadvantage of using these Trident chewing gums was the lack of color diversity, as the brand did not have cool colors (green, blue, indigo) on the market, which in mixture with warm colors would have resulted in a shade variability that would have been easier to assess.

Participants were instructed to chew gum specimens for 20 chewing cycles. It has been shown that at 20 chewing cycles, the tests show the best discrimination between subjects or different oral characteristics [30]. More than 25 cycles patients with integral dentition almost reach the saturation level of the color mixture, and thus the test loses its ability to quantify masticatory performance due to a plateauing effect of the results.

Each specimen was pressed between two glass plates until specimen thicknesses of approximately 1 mm were obtained. Prinz (1999) concluded that flattening of specimens leads to more accurate results compared to an evaluation of unworked specimens as they result from the mastication process [31].

A study with a similar methodology is Schimmel., *et al*. (2022), who used two different smartphones to take the photographs and compared the images with those obtained by scanning [32]. When

the images obtained with iPhone (Apple Inc.) and Samsung (Samsung Electronics Co., Ltd.), cell phones were compared with the gold standard, (represented by the scanner), there were significant differences between iPhone and scanner and between Samsung and scanner, yielding results indicating lower masticatory performance (higher VoH values) in the dentate and edentulous groups. The mobile phones used in our study belong to older generations and have inferior technical characteristics to the model used in the present study, but the results obtained by them are probably due to the standardized photography protocol on the one hand and to the larger group of study participants on the other hand. Although the results of our study provide some useful insights into the use of the cell phone camera in the clinical setting, they are not fully representative. The lack of standardization of the photography protocol resulted in photographs with variable technical characteristics. Standardizing camera settings is the first step towards reproducible images: selecting image resolution and aspect ratio, adjusting white balance, setting brightness, identifying the area of interest in the image and focusing by tapping the screen in the desired area, disabling flash and HDR. Of the environmental factors, using an additional light source would have improved the shooting protocol. In order to simulate the working conditions in a dental office, the images were not processed, but were entered into the ViewGum software in the form originally obtained. With some basic adjustments such as adjusting saturation, contrast and sharpening, the initial images could have provided more accurate data for evaluation purposes. Involving multiple operators in the subjective assessment could significantly improve the quality and reliability of the assessment by reducing biases, averaging multiple individual values, which can help eliminate outliers in the data, leading to more accurate results. Errors are more likely to be identified and corrected when several people review the same material. The diversity of perspectives can contribute to a more detailed and nuanced assessment, and an assessment by a more diverse group may be perceived as more credible and accurate than an assessment by a small number of operators.

The study of van der Bilt., *et al*. (2012) [33]. aimed to evaluate two methods of assessing masticatory performance using the two-color wax test: visual evaluation and digital image processing. In the visual evaluation method, an expert visually examined the chewed wax and subjectively assessed the extent of color mixing. In contrast, the digital image processing approach utilized specialized software to objectively analyze the color pattern of the wax and measure the degree of mixing. The results revealed that digital image processing provided more accurate and consistent measurements of masticatory performance compared to visual assessment. In another study Schimmel compared two different approaches for evaluating masticatory efficiency using the two-color chewing gum test [21]. The study aimed to assess the effectiveness and reliability of these methods, which involved both visual evaluation and digital image processing and the results confirmed the higher masticatory efficiency of dentate individuals.

Conclusion

The present study showed that the two-color chewing gum assessment method can also be applied with the mobile phone camera. Both the subjective and the objective methods were able to distinguish between the samples of patients with intact dentition and those with total dentures, but the subjective method was superior. This study indicated that the chewing gum test for the assessment of masticatory function is a reliable, non-invasive and readily applicable method for assessing and monitoring masticatory efficiency in complete denture wearers for both clinical and research purposes.

This study is consistent with the challenges faced by edentulous patients in terms of chewing function, as prosthetic devices may not restore the masticatory capabilities of natural teeth.

It is therefore highly recommended that all medical practitioners, especially general practitioners, actively participate in the diagnosis and treatment of masticatory dysfunction. This can be achieved by referring them to the dentist or by offering medical advice to patients through telemedicine.

Conflict of Interest

- There is no financial interest
- There is no conflict of interest

Acknowledgements

We want to thank to Niculae Andreea Mihaela, Teaching Assistant at the Department of Economic Informatics and Cybernetics, in University of Economic Studies, Bucharest, Romania, for the valuable statistical analyses conducted in support of this work.

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