Compensating for tooth loss in fully edentulous patients using complete dentures provides adequate physical, functional, and psychologic rehabilitation. Restoring the masticatory function is critical for preserving the patient’s health, as appropriate masticatory function is crucial for a healthy nutritional status.1 Good masticatory performance is related to dental conditions. Individuals with complete natural dentition show higher masticatory performance rates, while edentulous individuals show minimal performance.2 However, according to the type of restoration and the type of rehabilitation procedure, there are intermediate rates between the two extremes. The All-on-4 treatment concept (Nobel Biocare) has gained popularity in the rehabilitation of full-arch cases. Recently, it was reported as a modern technique in fixed complete denture rehabilitation on implants in a study by Malo et al.3 All-on-4 implant-supported fixed complete dentures were initially used to restore the excessively resorbed mandible, where the mental foramen was at the same level as the crestal bone. Posterior implants were tilted backward toward the mental foramina with a mesial angle of 30 degrees.4 Besides the tilted implants, the All-on-4 concept consists of having a shortened dental arch, with 10 or 12 teeth that may be terminated on the first molar site.

During chewing, food is ground and reduced in size, while saliva moistens and binds it into a bolus that can be easily swallowed. When the food particles meet the individual criteria for swallowing, they transit through the pharynx. This is referred to as the swallowing threshold.5 The quality of chewing can be evaluated in terms of “masticatory performance,” which is defined as the percentage of particle size distribution of food when chewed for a given number of strokes.2 It is affected by several factors, namely, the number of teeth in functional occlusion,6 the maximal occlusal force, and denture wearing.7 The individual’s capacity to grind and pulverize a test food after a fixed number of chewing cycles determines its masticatory efficiency.8

Masticatory Efficiency in Implant-Supported Fixed Complete Dentures Compared with Conventional Dentures: A Randomized Clinical Trial by Color-Mixing Analysis Test

Elie Jasser, DDS1/Zahraa Salami, DDS1/Fady El Hage2/Joseph Makzoumé, DDS, MSc, PhD3/Paul Jamil Boulos, DDS, MSc, PhD4

Purpose: To compare the masticatory efficiency of an All-on-4 prosthesis with complete dentures on a Class I ridge with a color-mixing analysis test. Materials and Methods: Ten patients with fixed complete dentures on implants and an additional 10 patients with conventional complete dentures on a Class I ridge (Atwood) chewed a bicolor chewing gum (Hubba Bubba) for different numbers of cycles (5, 10, 15, and 20). The chewed gum was retrieved, scanned, and weighted to quantify masticatory efficiency. Results: This study showed higher values for implant-supported fixed complete dentures than conventional complete dentures. These findings were significant with the color-mixing test in cycles 5 and 10 between both groups. The reduction in weight was not significantly different between the two groups but was noteworthy in intercycle comparison. Conclusion: Implant-supported fixed complete dentures showed superior masticatory efficiency compared with conventional complete dentures constructed over well-formed ridges in the early chewing cycles. Int J Oral Maxillofac Implants 2020;35:599–606. doi: 10.11607/jomi.7911

Keywords: complete denture, implant-fixed denture, masticatory efficiency, mixing ability test
Subjective assessment of masticatory performance, such as using a questionnaire, can be informative, but it is not reliable, especially when dealing with elderly patients due to their reduced communicative and cognitive abilities. On the other hand, objective laboratory-oriented and data-driven methods are more dependable in assessing masticatory function. The key point in these methods is to improve the individual masticatory efficiency by ensuring that particles ground by mastication reach the smallest-diameter sieves. Diversity in natural test foods exists, such as peanuts, hazelnuts, carrots, ham, coconut, lettuce, celery, apple, almonds, sardines, beef, sausage, etc. In addition to the natural test foods, artificial materials also have been used in masticatory efficiency tests. These include optical tests, made from condensation silicone Optosil (Kulzer), modified gelatin, and chewing gum, among others. Two-color chewing gum has been used as a test food for the quantification of masticatory performance and evaluating the ability to mix and knead a food bolus. Reliable and valid studies have shown that mixing ability tests are a trustworthy substitute for comminution tests.

Implant-retained dentures function similarly to conventional complete dentures, which are predominantly ridge-supported, but appliance retention and stabilization are vastly improved by the fixing effect of the implants. A literature review reported that implant-retained or supported prostheses produced a greater occlusal force and masticatory efficiency than conventional dentures in most of the studies. The instability of complete denture prostheses, biomechanically speaking, sensitizes and imbalances the electrical activity of the temporal musculature. This musculature is fatigued by complete dentures due to many factors, such as instability and masticatory inefficiency inherent to this type of prosthesis. It becomes overactive at rest while maintaining posture.

Different studies revealed progress in masticatory efficiency between implant-retained and conventional dentures. Setz et al revealed larger and more stable chewing patterns with mandibular fixed complete dentures on implants compared with their former dentures without implants. Similar conclusions were drawn by Carlsson and Lindquist, where masticatory efficiency and occlusal force improved.

On the other hand, the shape of the residual ridge has an influence on the support and retention of complete dentures. The results of the swallowing threshold of subjects with implant-retained prostheses were comparable to those of subjects with complete prostheses on a “high” mandible.

The objective of this study was to clinically compare the masticatory efficiency of edentulous patients rehabilitated with conventional and fixed complete implant-supported dentures using a two-color gum-chewing test. The null hypothesis of this study was as follows: Fixed complete implant-supported dentures have a masticatory efficiency superior to that of conventional dentures constructed over well-formed ridges.

MATERIALS AND METHODS

The clinical study protocol was submitted to the Ethics Committee of the faculty and approved in accordance with the report No. 2017-65. An informed consent was obtained from all participants in the study.

Twenty patient volunteers of both sexes were randomly selected from the list of patients treated in the postgraduate prosthodontics department at Saint Joseph University of Beirut. Their ages ranged from 40 to 60 years. The patients were divided into two groups. The first group had bimaxillary conventional complete dentures, and the second group had been restored with fixed complete implant-supported dentures according to the All-on-4 concept on either arch. The patients were selected randomly by computer sorting. Patients who did not have good general health, good intraoral conditions, and dentures in satisfactory conditions over the edentulous high ridge Atwood’s Class II were excluded from the study. The minimum time of complete denture use ranged from 3 to 6 months. All subjects did not present any temporomandibular dysfunction.

Two-color commercially available soft pink and azure chewing gum (Hubba-Bubba, Mars) was used to make two-color gum samples of 10 × 10 × 2 mm. The two color gums were manually pasted together with a drop of water. Patients were taught to chew naturally for an exact number of cycles (5, 10, 15, and 20 successive cycles).

The retrieved chewing gum was placed between two clear cellophane sheets, then squeezed and flattened with a mold consisting of two connected hard acrylic glass plates with an embedded 80 × 80 × 1-mm frame. Afterward, each sample was placed under a glass plate and photographed from both sides with a digital camera with a 16-megapixel sensor, fixed focal-length lens, under standard 5,500-K LED lighting.

In addition, each sample was weighted with a precision digital scale (with a 0.001-g tolerance) before chewing and recorded for each patient with the precise number of cycles. The gum was dehydrated on a paper drop of water. Patients were taught to chew naturally under sunlight for 2 days and weighted after chewing.

Images of both sides of the sample were subsequently copied and merged into one image. The compound images were then assessed with a purpose-built program, which is available through View Gum software (dHAL Software, Greece, www.dhal.com). The software first transforms the images into the HSI (Hue Saturation Intensity) color space.
Intensity) color space. It then calculates the hue value for each pixel in the semi-automatically segmented images. If the colors of the specimen are not mixed, two well-separated peaks on the hue axis are present. With increasing degrees of color mixing, the two hue peaks of each color group converge and will eventually fuse at an intermediate position into one peak where the colors are perfectly mixed. Hence, inadequate mixing will be represented with a larger variance on the hue axis compared with complete mixing. The variance of the hue (VOH) is considered the measuring criteria for blending effect. This method was originally described by Halazonetis et al.\(^\text{11}\) (Figs 1 to 3).

**RESULTS**

SPSS statistical software (version 22.0) was used for statistical analysis of the data. The significance threshold used corresponds to a \(P\) value \(\leq .05\). The primary criterion of the study was the value of standard deviation of hue. The second criterion was the difference between the initial weight and the weight after chewing the gum.

Kolmogorov-Smirnov tests were conducted to assess the normality of the distribution of quantitative variables.

The standard deviation of hue was studied according to the type of prosthesis (All-on-4, conventional complete denture) and according to the number of masticatory cycles (5, 10, 15, and 20 cycles). Repeated measurements of variances including intersubject factor (prosthetic treatment) and intrasubject factor (cycles) were conducted. These tests were followed by univariate analysis and multiple comparisons of Sidak.

**Evaluation of Hue Score at Group Level**

The mean and standard deviation of the hue deviation score as described previously and according to the type of prosthesis and the number of masticatory cycles are reported in Table 1 and Fig 4.
Comparison Between Cycles

The standard deviation of hue significantly decreased during masticatory cycles in patients with conventional prostheses ($P = .002$). This decrease was significant between cycle 5 and cycle 15 ($P = .014$), and cycle 5 and cycle 20 ($P = .003$). Masticatory efficiency was significant between cycles in the conventional prosthesis group, and significant results were found between cycle 5 and cycles 10, 15, and 20, respectively. Results are shown in Table 2.

Comparison Between Prosthesis Types

This study showed that the standard deviation of hue was significantly lower in patients wearing an All-on-4 prosthesis compared with those wearing a conventional prosthesis, and this was true for cycles 5 ($P = .009$) and 10 ($P = .024$). Masticatory efficiency was significantly higher in All-on-4 groups than conventional groups in cycles 5 and 10. After 10 cycles (15 and 20), there was no significant difference between both groups.

Assessment of the Chewing Gum's Weight at Group Level

The mean and standard deviation of the reduction in chewing gum weight according to the type of prosthesis and the number of masticatory cycles are illustrated in Table 3 and Fig 5.

Comparison Between Cycles

The reduction in chewing gum weight significantly increased during masticatory cycles in patients with an All-on-4 prosthesis ($P < .001$). This increase was significant between cycle 5 and cycle 10 ($P = .017$), and cycle 10 and cycle 15 ($P = .05$); however, the difference was not significant between cycle 15 and cycle 20 ($P = .366$). The decrease in weight was significantly augmented during masticatory cycles in patients with conventional prostheses ($P < .001$). This upsurge was significant between cycle 5 and cycle 10 ($P = .011$), and cycle 10 and cycle 15 ($P = .012$); however, the difference was not significant between cycle 15 and cycle 20 ($P = .070$). Thus, masticatory efficiency by weight reduction was not significant in both groups, but results showed significant values between cycles 5 and 10 and 10 and 15 in both groups.

Comparison Between Prosthesis Types

This study showed that the reduction in the weight of chewing gum was not significantly different between patients with conventional prostheses and those with All-on-4 prostheses for cycles 5 ($P = .737$), 10 ($P = .699$), 15 ($P = .425$), and 20 ($P = .231$).

DISCUSSION

This study was based on a feasible scanning method, which dramatically reduces the time required for the processing of chewed artificial
test food samples. Patients with complete dentures or implant-supported fixed complete dentures chewed a bicolor chewing gum for different numbers of cycles. Chewed gum was retrieved, scanned, and weighted to quantify masticatory efficiency. The main objective was to compare the masticatory effectiveness between All-on-4 prostheses and conventional complete dentures with this more practical and less-expensive method. The results of this study showed higher values for fixed complete implant-supported dentures than for conventional dentures. These findings were significantly different in the color-mixing test in cycles 5 and 10 between both groups (Table 1). The reduction in weight was not significant between the two groups but was more pronounced in intercycle measurements (Table 3).

For several years, the sieving method has demonstrated good reliability. Its validity has been established by strong correlations with factors such as the number of missing teeth, mastication cycles, and the lost occlusal area. This method uses a standardized food, unlike tested natural foods such as almonds, carrots, and peanuts. Sieving of sliced food particles is an extremely time-consuming and sensitive technique for masticatory efficacy testing. Condensation silicone also requires sieving or a scanning technique to capture different particle sizes. The new scanning method is practical and significantly reduces the time required for processing the samples. In addition, the equipment is less expensive than the sieving technique armamentarium. The two-color gum is easy to chew and forms a bolus. In addition, it has been reported that the size and hardness of food change during mastication causes ambiguity when comparing different types of food. To eliminate this ambiguity, a chewing gum was chosen as the test bolus in this experiment, since it did not change much in either size or hardness during mastication. This makes this test more appropriate for elderly patients and yields predictable results compared with the fragmentation test. The gum loses up to 40% of its volume after only 20 cycles of chewing, but this does not affect the results because the hue variance, and not the actual value, was the measure of choice by the software used.

Digital images of the chewed bolus were captured after being flattened to avoid shadows in the image due to the oblique illumination of the lamp. The flattening of the chewed bolus did not have a significant effect on the degree of color mixing determined from the image analysis. This procedure allows for a more accurate bolus evaluation than the bolus examination in its raw state, and the examiners reported finding the flattened bolus evaluation easier. Computer analysis can determine different numeric parameters of images, such as unmixed color areas and areas of different intensities. The two-color chewing gum test has been sufficiently documented as a simple and effective test that can be used in a clinical setting. This time-efficient procedure requires a few minutes of patients’ time: chewing gum for 20 cycles and a few more minutes to flatten it to a 1-mm-thick wafer, scan it, and evaluate it electronically.

An important prerequisite for conclusive results is the choice of the gum, which must have two distinct and well-contrasted colors. White or gray gum should be avoided because they are undefined colors and are very close in the hue axis in the HSI (space system). Similarly, gum colors deriving from different saturations of the same hue, such as pink or red, should be avoided.

### Table 3 Decrease in Weight (g) According to Prosthesis and Masticatory Cycle

<table>
<thead>
<tr>
<th>Cycle</th>
<th>All-on-4 (n = 10)</th>
<th>Conventional prosthesis (n = 10)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.092 ± 0.045a</td>
<td>0.100 ± 0.060a</td>
<td>.737</td>
</tr>
<tr>
<td>10</td>
<td>0.172 ± 0.075b</td>
<td>0.185 ± 0.077b</td>
<td>.699</td>
</tr>
<tr>
<td>15</td>
<td>0.254 ± 0.113c</td>
<td>0.285 ± 0.046c</td>
<td>.425</td>
</tr>
<tr>
<td>20</td>
<td>0.296 ± 0.104c</td>
<td>0.348 ± 0.080c</td>
<td>.231</td>
</tr>
</tbody>
</table>

*Same superscript letters in a column indicate no significant difference.*
For this reason, Hubba Bubba gum was used in this study with both pink and azure colors; these two colors were the same colors used by the software as calibration gum. The results presented in this study are valid for the specific gums mentioned and for a scanning thickness of 1 mm, as previously suggested. Other flattening thicknesses may produce different values. These have not been studied.

Dellavia et al evaluated the electromyographic (EMG) characteristics of masticatory muscles in patients with fixed implant-supported prostheses according to All-on-4 principles, in complete denture patients, and in control with healthy dentate subjects. Masseter and temporalis muscle and maximum voluntary teeth clenching during unilateral gum chewing were examined with EMG. The neuromuscular balance, mastication frequency, and working-side muscle activities were found to be good in all patients during clenching. In EMG parameters, there was no significant difference between All-on-4 implant-supported prostheses and natural dentition subjects. This is in contrast with complete denture wearers. In their study, the All-on-4 prosthesis was proposed to be used functionally in edentulous patients and positively affected mastication activity. Similar results were shown in the present study; higher values for implant-supported fixed complete dentures compared with removable ones were found in both tests (Tables 1 to 3). Even though those results were not significantly higher in all cases, it was obvious that the values were always noticeably higher for the implant-supported fixed complete dentures. Setzer et al revealed larger and more stable chewing patterns with implant-supported full mandibular prostheses compared with patients’ older conventional dentures. Carlsson and Lindquist followed a number of edentulous patients with mandibular implant-supported fixed prostheses and conventional complete dentures over a period of 10 years posttreatment. They found that the occlusal force increased for both types of treatments; it ranged from 80 N for conventional dentures to 240 N for fixed prostheses, and patients’ masticatory efficiency improved as well. In another study, Pera et al evaluated the masticatory efficiency and the patient satisfaction for completely edentulous patients who were then rehabilitated with complete removable prostheses before and after being anchored to implants. They noted that masticatory cycles increased in amplitude after anchoring to implants.

Hiasahi et al found that the shape of the residual ridge has an influence on the support and retention of the complete denture. This support is the most important factor for masticatory function in complete dentures; therefore, it must be well supported against the occlusal force and with a denture-bearing area composed of soft tissue. It follows that a larger bearing area is needed to eat hard food by providing a bigger area of support. In this study, patients with a Class I ridge (Atwood classification) were included; patients with a well-formed ridge were selected. Thexton found that the swallowing threshold of subjects with prostheses stabilized by implants or by the natural roots were on average comparable to those of subjects with complete prostheses on a “high” mandible. This is consistent with the results of this study in cycles 15 and 20, where there was no significant difference in masticatory efficiency between both groups. On the other hand, Speksnijder et al found that implant retention of the denture had a significant, positive effect on the ability to mix the two-color wax. In contrast, they also found that the mixing ability test demonstrated significant differences between the two denture groups after 15 and 20 chewing cycles. These findings might be due to their use of colored wax and not chewing gum.

Normally, between 10 and 20 chewing cycles are recommended to prepare food for swallowing. It has been shown that this number varies from person to person. Since the average chewing frequency is stable and approximately 1.35 Hz, chewing for 20 seconds should be used as an alternative. For the present study, the results showed that there was a significant difference between both groups in cycles 5 and 10, in the early cycles of chewing, and a nonsignificant difference in the long-term chewing cycles, cycles 15 and 20, between both groups (Table 1). Nevertheless, Shiga et al concluded that bolus size positively affected the spatial and temporal parameters of mastication. Since gum volume is small (volume = 0.2 mm³), mastication should be efficient in the early cycles or for a shorter time. According to the results of this study, patients have the ability to reach the swallowing threshold more easily with implant-supported fixed complete dentures than with conventional complete dentures, whose wearers need to achieve more chewing cycles in order to compete with the implant prosthesis wearers. It was interesting to note that these subjects compensated for their low initial masticatory performance with prolonged mastication (15 and 20 cycles) to achieve a better comminution of food at the time of swallowing. This might result in muscle fatigue and dysfunction in conventional complete denture wearers.

Poyiadjis and Likeman dehydrated and weighted the gum after chewing. The weight after chewing was compared with that before chewing, and a reduction was attributed to the amount of sugar lost during chewing. Therefore, the greater the loss of sugar, the more effective the chewing. In a similar study, Anastasiadou and Heath developed an objective chewing test with chewing gum suitable for the elderly. They defined masticatory efficiency as the percentage of weight of the original gum that was chewed in
a defined number of strokes. Chewing gum weight reduction significantly increased during masticatory cycles in patients with All-on-4 prostheses and patients with conventional prostheses in the present study, but this decrease was not noticeably significantly different between the two groups. The reduction in chewing gum weight significantly increased during masticatory cycles in patients of both groups (P < .001). This increase was significant in intercycle measurements, but the difference was insignificant between cycle 15 and cycle 20. The tested chewing gum sometimes adhered to the prostheses, which biased the test, and thus, the retrieval of test material would be more difficult and the results prone to error. This problem was solved in some studies by packing the test food in a finger cot, to keep the fragmented particles collected. In addition, while drying the chewing gum, the difference in viscosity of saliva, secretion, and its components varies between different patients, and this may adversely affect the results. Those issues made the weight loss a secondary criterion in this study.

**Limitations of the Study**

The limitations of the study were as follows:

1. Patients of both sexes and of different ages were selected. This may cause discrepancy in chewing level and masticatory efficiency between all groups.
2. The gum occasionally adhered to the prostheses, which may make the results in these cases questionable.
3. The pattern of chewing cycle was not regular between the patients. The patients were free to chew at their convenience.

Within the aforementioned limitations, the null hypothesis of this study was validated; implant-supported fixed complete dentures have a masticatory efficiency superior to that of conventional dentures constructed over well-formed ridges.

Future work prospects must include new studies using the same methods but with different criteria. Ridge height changing and patients’ sex, age, and number of implants should be taken into consideration, leading to new insights in comparing masticatory efficiency between implant-supported fixed and complete dentures in future studies.

**CONCLUSIONS**

Masticatory efficiency was compared between implant-supported fixed complete dentures and conventional complete dentures using the color-mixing test. A two-color chewing gum was used to evaluate this efficacy by color mixing and gum weight loss. The results of this study show that there was a correlation, albeit not significant, between the two different evaluation methods. Notwithstanding, this difference was significant between the implant-supported fixed and the conventional prostheses as shown by the color-mixing test.

**ACKNOWLEDGMENTS**

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**REFERENCES**