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ORIGINAL ARTICLE

Reliability between the two-colour chewing gum and the gummy-jelly tests used for the assessment of masticatory performance

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Abstract

Objective: This study aimed to evaluate the reliability of two methods used to assess masticatory performance and attempt to correlate them to achieve interchangeability between the methods.

Methods: Twelve healthy dentate volunteers (men = 6, women = 6; mean age = 28.3 ± 4.1) with no known dental or medical pathologies were requested to participate in this study. Each participant completed three masticatory performance assessments, including two two-colour mixing-ability tests using chewing-gums (CG: gum#1 and gum#2) and the gummy-jelly (GJ) test. For each method, participants created five samples each (total = 15 measurements per participant, gum#1 = 5, gum#2 = 5, GJ = 5). For the gum#1 and gum#2 methods, the predetermined chewing cycles were fixed at 10, 15, 20, 25 and 30 cycles, and for the GJ method, the time duration was fixed at 10, 15, 20, 25 and 30 s. The parameter measures were submitted to Z-score transformation, and Bland–Altman plots were generated to graphically compare the differences between two techniques against their means. Additionally, mountain plot was used to assess the cumulative distribution of measurement error between the methods.

Results: A total of 180 measurements were recorded. There were significant correlations between the number of chewing cycles/chewing time and masticatory performance using the gum#1 ($r = -.753$; $p < .001$), gum#2 ($r = -.838$; $p < .001$) and GJ ($r = .730$). When all tests were considered together for each method, significant correlations were found ($p < .001$). A descriptive range of mean values aiming to produce reference value ranges for predictive purposes was achieved considering the interchangeably among the methods [CG = GJ (VoH-mg = dL): 10 cycle = 10 s: 0.329 = 110; 15 cycles = 15 s: 0.177 = 164; 20 cycles = 20 s: 0.130 = 205; 25 cycles = 25 s: 0.086 = 200; 30 cycles = 30 s: 0.077 = 267].

Conclusion: The strong correlations and high consistency between the two masticatory performance methods found in this study conclude that the two assessment

methods are reliable and interchangeable. Further evaluations are warranted to arrive at a conversion formula for translation of the results between the two methods.

KEYWORDS
geriatric dentistry, Gluco-sensor GS II, gummy-jelly method, masticatory performance, two-colour mixing-ability

1 | INTRODUCTION

Several dynamic tests assess masticatory function. The frequently employed assessments include comminution tests, mixing ability tests and shearing tests, which all provide valuable insights into the effectiveness of the chewing process.[1] Among these tests, the sieving method is the most employed and remains the "gold standard" for assessing chewing function. In this method, the subjects chew a specified test food for a predetermined number of cycles. The resultant crushed material is then collected and sifted through a series of sieves and the chewing efficiency is assessed based on the particle sizes achieved by the degree of crushing during the chewing function. Although this test is a reliable method, it is beset by challenges arising from its intricate procedures and the substantial time investment required for the test.[2] Furthermore, various test foods are employed and are not universally standardised, which is a frequent problem with this test and complicates the interpretation and comparability of the results.[2]

Recently, a shift towards simpler evaluation techniques for the assessing masticatory performance has occurred, and these techniques employ novel test materials including chewing gum,[3,4] paraffin wax,[5] or gummy jelly.[1,2,6,7] The chewing gum methods have been more frequently used in recent times and have gained popularity because of their ease of use, making them less cumbersome and less time-consuming. This method involves chewing either colour-changing chewing gums or two-colour chewing gum for a specified number of chewing cycles (depending on the method). The masticatory performance is assessed by evaluating the colour change or the colour mixing achieved. The test assesses chewing function by analysing the almost logarithmic decay of the colours during a given number of chewing movements.[3,4] Among the newer alternatives, the gummy-jelly technique employs a glucose extraction method from a gummy jelly containing a predetermined quantity of glucose that elutes the glucose during chewing. The eluted glucose is measured using a device, and the quantity of the eluted glucose quantifies masticatory performance.[4,8–10]

Although all the fore explained methods for masticatory performance are validated, reliable and provide meaningful information, they cannot be interchangeable or comparable. Each test employs a different protocol, materials and methods, as well as quantifies the assessments differently and cannot be translated. Most importantly, for research purposes, it is impossible to compare results from studies that have assessed masticatory performances but have used different methods and materials.

Having a single universally accepted standardised method for assessing masticatory performance is beneficial; however, may not be an immediate occurrence. Therefore, a bridge between two validated methods might be a more accessible and quicker solution. Hence, the aim of this study was to evaluate the reliability of two different methods used for the assessment of masticatory performance and attempt to correlate them to achieve a conversion scale to achieve interchangeability of the methods.

2 | MATERIALS AND METHODS

2.1 | Ethics statement

The study received ethics approval (BASEC-Nr. 2023–00297) from the relevant ethics committee from the state of Zurich in Switzerland (Kantonale Ethikkommission Zurich). An ethics approval was requested to quantify a measurable scale for the validated two-colour chewing gum method used in assessing the masticatory performance and correlating the chewing gum with the validated gummy-jelly (GS-II) methods. The current paper reports on the reliability between the two methods.

2.2 | Participants

Participants were recruited from the staff who worked in the Clinic of General- Special care- and Geriatric Dentistry (ABS) in the Center of Dental Medicine (ZZM) at the University of Zurich in Switzerland. Equal numbers of men and women were recruited in this study. The volunteers were excluded if they had fewer than 28 teeth, if they complained of any pain during the time of the assessments, and if they reported any existing dental or temporomandibular-related problems.

2.3 | Masticatory performance tests

Two methods for testing masticatory performance, the two-coloured chewing gum test and the gummy jelly test, were evaluated in the current study.

2.3.1 | Two-coloured chewing gum method

The masticatory performance method described by Schimmel and coworkers, using the two-colour chewing gum, was performed

in this study.[4,11–13] For this purpose, two validated chewing gums (chewing gum #1: Hue-Check Gum©; University of Bern, Switzerland; Chewing gum #2: Vivident Xylit Fruitswing Karpuz/Asai ÜzÜmÜ, Perfetti van Melle, Turkey) were used; both of these chewing gums have been frequently employed in multiple studies of similar nature.[4,11–16]

The validated protocol recommends that the chewing gum be chewed for 20 cycles.[4,11–13] The chewed gum is collected in a transparent cellophane pouch and visually assessed to be graded subjectively between SA1 and SA5, with SA1 being poor and SA5 being the best performance. The collected gum is then flattened to a wafer thickness of 1 mm. Both faces of the flattened wafer are then scanned using a standard photo scanner (Epson Perfection V800 Photo Scanner; Epson America, CA, USA) with a minimum resolution of 500 dots per inch (dpi) to create a single image file (.jpeg/.jpg file format). The two scans of the chewing gums are then imported into commercial photo editing software (Adobe Photoshop® Elements for Windows, Adobe systems incorporated, San Jose, CA, USA) to incorporate them in a single image. This image was then imported into a purpose-built free software used for determining the variance of hue (VoH) (ViewGum software, dHAL Software, Kifissia, Greece).[17] The VoH quantified the masticatory performance based on the colour mixing accomplished by the participant's chewing performance.

For experimental standardisation in this study, the number of cycles selected was fixed with two steps above and two below the recommended chewing cycles of 20, hence five chewing cycles were employed (10, 15, 20, 25 and 30). Therefore, each participant created five samples of the test gum for 10, 15, 20, 25 and 30 chewing cycles. Each participant was requested to chew gum #1 at the stipulated chewing cycles of 10, 15, 20, 25 and 30. The participants were requested to repeat the procedure for gum #2. These were accomplished over 2 days. The sequence of the chewing cycle for each gum for the participant was randomised as recommended in previously published validation studies.[8]

2.3.2 | Gummy jelly (GS-II) method

The gummy jelly method employs a device (Gluco Sensor GS-II, GC Corporation, Japan) that measures the glucose content in the saliva after the participant has completed chewing the purpose-manufactured gummy jelly (Glucolumn GS-II, GC Corporation, Japan).[2,18] The participant was asked to chew on the 2 g test gummy jelly containing glucose for 20 s. The participant is then requested to sip 20 mL of water, rinse the mouth empty with this water and expel the chewed jelly along with the water in a measuring cylinder. The quantity of glucose eluted (in mg/dL) from the jelly is measured with the GS-II device. Similarly, as with the chewing gum tests, the chewing cycle time was also decreased two steps below and two steps above the recommended cycle of 20s. Therefore, each participant made five samples each at 10, 15, 20, 25 and 30 s. The samples were collected over 5 days for the gummy-jelly method.

2.4 | Study protocol

Two investigators (A. N. and L. T.) requested the staff of the ABS clinic to participate in this experimental study. The details and purpose of the study were briefly explained to the volunteers in the local language (Swiss-German), and they were recruited upon receiving consent. Equal numbers of men and women were recruited in the study. Each participant was requested to complete the masticatory performance assessment methods, the two-coloured mixing test and the gummy-jelly method, as detailed in the above sections. All the samples were collected, and the necessary assessments/evaluations of the samples were performed, as per the recommended protocols, by the same two investigators (A. N. and L. T.), who were involved in the screening and recruitment of the participants. Maximum bite force (MBF) was measured using a digital force gauge (Occlusal Force-Meter GM_10, Nagano KEIKI Co.), recorded in triplicate on both sides in the molar area, and then the mean MBF was calculated.

2.5 | Sample size

The required sample size for the current study using an effect size $|\rho| = .7071$ and a coefficient of determination (r^2) = .5, with α err prob = .1 and a power of (1-β err prob) of 0.9 (90%) was calculated to be 11 participants. The calculated actual power for the sample size of 11 was found to be 92% ($\delta = 3.317$; Critical $t = 1.833$; Df = 9). Assuming a dropout rate of 10%, the final total sample size was fixed at 12. In the case of non-significant correlations, a post-hoc sample size calculation was planned. The sample size calculation was performed using a validated free software (G*Power, version 3.1.9.6 for Mac OS X 10.7 to 14, Düsseldorf, Germany).[19,20]

2.6 | Data analysis

Data analysis included descriptive statistics and bivariate correlation analysis. The normality of data was assessed using the Shapiro–Wilk test since it is a more appropriate test for small sample sizes (<50 samples). Then, to test the reliability of the methods, the Bland–Altman plot was used as a graphical method to compare two measurement techniques by plotting the differences between the two techniques against their means. If the mean difference and the limits of agreement fall within ±1.96 times the standard deviation, the differences are deemed not clinically significant, and the two methods may be used interchangeably. Moreover, since there was more than one measurement per subject for each method, the Bland–Altman plot with multiple measurements per subject was adopted, and the true value was constant in each subject model.[21] Therefore, there was only one marker for each subject in the graph, and the marker size is relative to the number of observations for the subject.

In addition, a mountain plot (or "folded empirical cumulative distribution plot") was created by computing the percentile for

each ranked difference between the two MP methods and the gummy jelly, and the percentiles were then plotted against the differences between the two methods. The mountain plot was used to assess the cumulative distribution of measurement error between the gummy Jelly (reference method) and the mixing-ability tests and to compare the different methods. The plot interpretation infers that if two methods are unbiased concerning each other, the mountain will be centred over the zero value of the x-axis, and longer tails represent large differences between the methods. The IBM-SPP 24.0 and the MedCalc (version 20.118) software were used for data analysis.

3 | RESULTS

Data were obtained from 12 volunteers and aged 21 to 39 years-old (mean = 28.3; SD = 4.1), and six were female (50%). All subjects had a complete dentition with 28 teeth (except one with 24 teeth) and were free from oral pain or reduced salivary flow.

The null hypothesis that the data were normally distributed was not rejected for all the functional tests; therefore, parametric statistical methods were used. Table 1 summarises the data for the functional tests, including mean MBF and the VoH measures using the two chewing gums, and the amount of glucose content using the gummy jelly for the masticatory test. The values for the chewing tests were obtained for increasing the chewing cycle number or duration. There were significant correlations between the number of chewing cycles/chewing time and masticatory performance (MP) using the Hue-Check gum ($r = -.753$; $p < .001$), Fruitswing gum ($r = -.838$; $p < .001$) and gummy jelly ($r = .730$). Moreover, MBF was not correlated with the participant's age ($r = .018$; $p = .995$), and MBF was higher for men ($p = .045$).

When all tests were considered together for each method, significant correlations (Pearson correlation) were found, as shown in Table 2 and Figure 1. There was no correlation MBF and the masticatory performance methods ($p > .05$). On the other hand, all the MP methods were significantly correlated among them ($p < .001$).

Then, the MP parameter measures were submitted to Z-score transformation to standardise the data and be able to compare values between the different data ranges of the chewing gum tests (0–1) and the gummy jelly test (61–330). In addition, since better chewing performance has opposite directions using the two distinct methods, the signals of the gummy jelly test values were reversed, i.e. negative values were converted into positive, and vice versa. Therefore, Figure 2 shows the values (means and 95% confidence intervals) of the methods after data transformation, revealing that the methods were quite similar in their performance concerning the variation in the number of chewing cycles or performing time.

The standardised and standardised and reversed values were used to construct the Bland–Altman plots concerning the error measurements of the chewing gum and gummy jelly tests (Table 2). A visual analysis of the plots revealed low bias and no systematic error for the two chewing gum tests compared to the gummy jelly test. Moreover, the Mounting plot in Figure 3 showed that the two chewing gum tests are unbiased concerning the gummy jelly test since the mountain is closely centred over zero. The short tails in the plot revealed slight differences between the methods, since nearly 80% of the cases lie between ±1 standard deviation difference, and 100% of cases lie between ±2 standard deviation difference.

TABLE 1 Summary data of the functional parameters ($n = 12$).

Functional parameter	Test	Min–Max	Mean (SD)[b]
Maximum Bite Force (kN)	–	0.094–0.690	0.296 (0.160)
MP[a] – chewing gum #1 (VoH)[c]	10 cycles	0.151–0.502	0.336 (0.103)
	15 cycles	0.054–0.427	0.136 (0.104)
	20 cycles	0.040–0.180	0.099 (0.040)
	25 cycles	0.028–0.082	0.043 (0.014)
	30 cycles	0.023–0.149	0.044 (0.034)
MP – chewing gum #2 (VoH)	10 cycles	0.215–0.442	0.323 (0.066)
	15 cycles	0.131–0.284	0.217 (0.049)
	20 cycles	0.118–0.208	0.161 (0.032)
	25 cycles	0.099–0.181	0.129 (0.028)
	30 cycles	0.069–0.143	0.110 (0.026)
MP – gummy jelly (mg/dL)	10 s	61–173	110.1 (32.8)
	15 s	80–220	164.7 (41.6)
	20 s	120–375	205.8 (75.3)
	25 s	136–254	200.2 (29.6)
	30 s	205–330	267.1 (33.8)

[a]MP – Masticatory Performance.
[b]SD – Standard Deviation.
[c]VoH – Variance of Hue.

TABLE 2 Pearson correlation coefficients for the association between masticatory performance methods.

	Maximum Bite Force (kN)	MP chewing gum #1	MP chewing gum #2
MP – chewing gum #1	0.085 ($p = .520$)		
MP – chewing gum #2	0.024 ($p = .855$)	**0.855 ($p < .001$)**	
MP – gummy jelly	0.002 ($p = .986$)	**−0.645 ($p < .001$)**	**−0.740 ($p < .001$)**

Bold values are statistically significant.

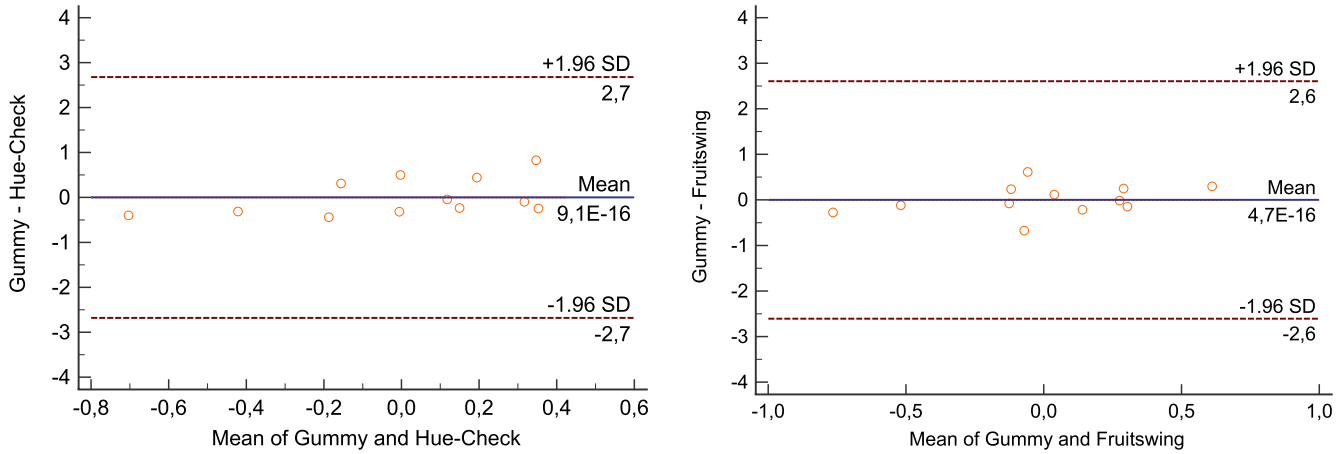
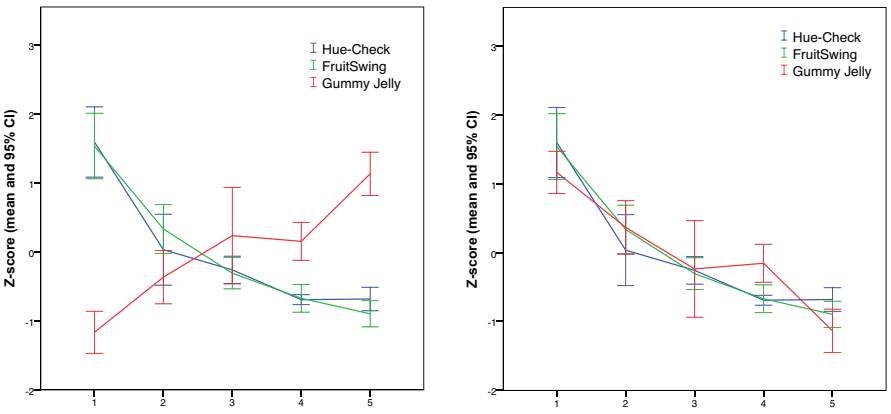


FIGURE 1 Bland–Altman plots for multiple measurements per subject, considering the gummy jelly as the reference method and the Hue-Check (left) and Fruitswing (right) chewing gums. Plots are based on Z-score-transformed values. The horizontal lines represent the mean difference and the limits of agreement between the two methods.

FIGURE 2 Means (and 95% confidence intervals) values obtained using the three methods for assessment of the masticatory performance. Left: data after Z-score transformation; Right: data after Z-score transformation and reversing the scores of the Gummy jelly test. The x-axis represents the 1–5 test conditions, respectively: 10, 15, 20, 25 and 30 chewing cycles for the chewing gums, and 10, 15, 20, 25 and 30 s for the Gummy Jelly.



Finally, considering the interchangeability among the methods, a descriptive range of mean values and scatterplot were provided in Table 3 and Figure 4, aiming to produce reference value ranges for predictive purposes.

4 | DISCUSSION

The findings of this study confirmed that all the tested methods to assess masticatory performance in the current study performed satisfactorily to discriminate different levels of masticatory efficiency and presented good consistency across the methods. Therefore, results suggest that the mixing-ability test with a two-coloured chewing gum and the gummy jelly with glucose quantification can be used interchangeably.

This study is of clinical relevance within the context of the assessment of subjects with impaired oral function. Currently, in pursuing a healthy life expectancy, a crucial emphasis has emerged on preserving and enhancing oral function. Maintaining a strong masticatory function is a fundamental pillar among the myriad of factors contributing to overall well-being. Effective masticatory function is crucial not only for properly breaking down food to enable safe swallowing without the risk of choking but also for supporting optimal digestion and nutrition; impairments in

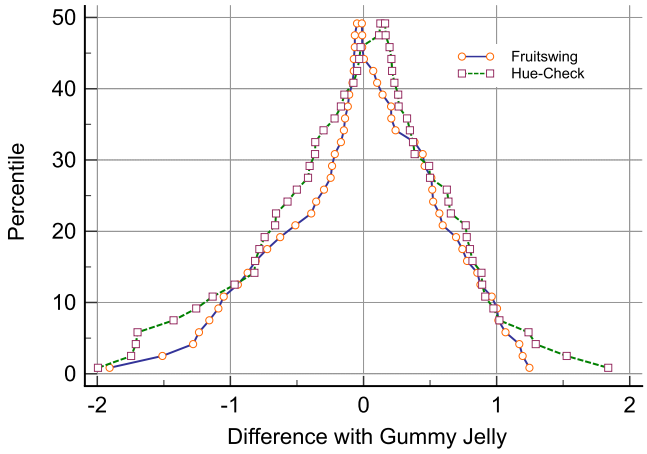


FIGURE 3 Mountain plot of the percentile for the ranked difference between the chewing gum methods and the gummy jelly (reference method). The MP parameter measures were submitted to Z-score transformation to standardise data and be able to compare values between the different data-ranges of the chewing gum tests and the gummy jelly tests.

TABLE 3 Paired correspondence of values between the mean values of chewing gum methods and the gummy jelly, according to the performance tests (1–5).

Test	Chewing gums	Gummy jelly
1	0.329	110
2	0.177	164
3	0.130	205
4	0.086	200
5	0.077	267

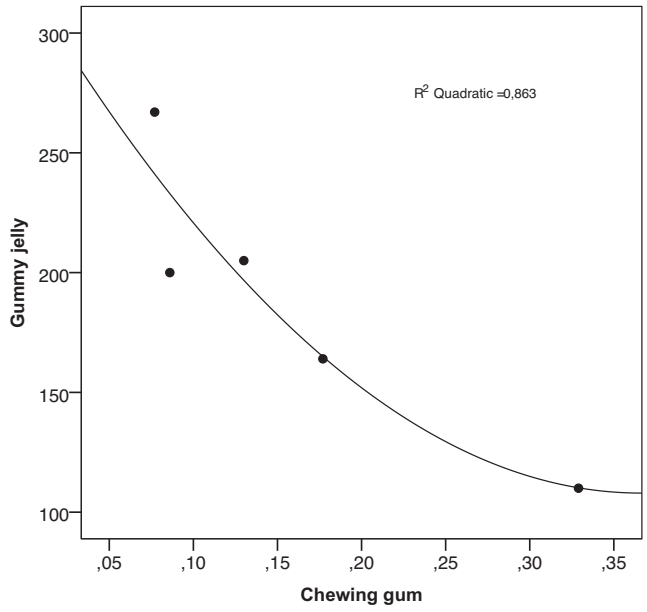


FIGURE 4 Scatterplot for prediction of the gummy jelly method based on the summary data of the two methods.

mastication can adversely impact both.[6,22] The repercussions of this decline can extend beyond oral health and crucially affect the overall well-being, especially in age-advanced frail older adults.[7,23] Therefore, assessing and monitoring masticatory performance in older adults is quite pertinent.

Currently, in clinical settings or as diagnostic tests, there is no established method for assessing masticatory performance with a strong level of evidence for all measurement properties, and several assessment methods with variable levels of evidence require lab-intensive equipment, such as sieves or digital image software.[24] However, mixing-ability methods that involve two-colour chewing gums, colour-changing chewing gum or waxes (as test foods) have been proposed as straightforward methods with good reliability when applied to patients with intact dentitions or with compromised dentitions rehabilitated with/without conventional or implant-supported removable prostheses.[24] Although most of these methods require optical and image processing devices, simplified measurements using visual boli/colour scales or smartphone camera images can be helpful in a clinical setting.[13] Nevertheless, in this study, an electronic colorimetric method was used to assess the level of mixing ability of the two-coloured chewing gums, which is quite sensitive to smaller changes in masticatory performance than visually based assessments with regard to the number of chewing cycles performed.[25] Moreover, the mixing-ability tests used in this study have good clinical applicability, are fast and easy to perform, efficient and economical and uses a free software.

The gummy jelly test is categorised under the comminution methods of assessment of the masticatory performance and involves measuring the glucose elution from the chewed test specimen (gummy jelly), and the amount of released glucose is associated with the degree to which test food is fragmented and hence corresponds to the masticatory performance.[24] The glucose metre measurement of the concentration of glucose dissolved from the comminuted particles demonstrates a high reproducibility and accuracy when the rinsing time, temperature of the distilled water and dissolution time of the glucose were strictly prescribed.[26] However, it was also been reported that the glucose metre and the use of a visual scoring scale provided fairly consistent outcomes in detecting oral hypofunction.[6]

Results also showed that the maximum bite force levels did not influence the masticatory performance in this group of patients. This is consistent with reports that have suggested that the mixing-ability tests rely primarily on the sensitivity, coordination and force of the oral musculature like the tongue, lips and cheeks.[8] On the other hand, it has been reported that the bite force may influence those masticatory performance tests that use comminution methods with hard test foods because this is important to crush and break down fragmentable foodstuff.[8]

Finally, this study was focused on the comparability between mixing-ability and glucose metre methods to assess if the two tests can be used interchangeably for clinical and research practices. This might be very useful to interconnect the various studies assessing masticatory performance in clinical and experimental scenarios.

The current study findings suggest that all the tested methods are reliable and provide reproducible results. It must be borne in mind that although the current experiments provide sound preliminary information, the fact that they were conducted in healthy young dentate adults can be considered a limitation. Therefore, extrapolation of these findings to older subjects with natural dentition or prosthetic rehabilitations should be considered with caution. Future studies evaluating these methods in a realistic clinical scenario involving patients with varied degrees of compromised dentitions, prosthetic rehabilitations and impaired oral functions are still warranted to confirm the current study findings.

5 | CONCLUSION

This study observed a strong correlation and a high consistency between the mixing-ability of two-coloured chewing gums and the gummy jelly methods. Therefore, these methods may be considered reliable and interchangeable for assessing masticatory performance. However, further studies are warranted to arrive at a conversion formula to aid in translating the results between the two methods to help clinicians provide a comprehensive prediction of the patient's oral function.

AUTHOR CONTRIBUTIONS

Arnold Nrecaj and Lisa Takeshita collected and analysed data, wrote the first draft of the manuscript and agreed on all changes. Yasmin Milhomens Moreira analysed data and wrote the first draft of the manuscript. Martin Schimmel and Claudio Rodrigues Leles analysed data and contributed to the final manuscript. Murali Srinivasan conceived the study, collected and analysed data and wrote the first draft and the final manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest concerning this study.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

Will be provided on request.

ETHICS STATEMENT

Approved by the Cantonal ethics commission of Zurich (BASEC-Nr. 2023–00297).

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