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Assessment of masticatory efficiency based on glucose concentration in orthodontic patients: A methodological study

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Abstract

Background: Treatment for malocclusion can cause discomfort and pain in the teeth and periodontium, which may impair masticatory efficiency. The glucose concentration method is widely used to assess masticatory efficiency for its convenience in the clinical situation, although its validity has not been shown.

Objectives: The aims were to determine the validity of the glucose concentration method and investigate if this method can be applicable to orthodontic patients with braces.

Method: Sixteen healthy individuals (7 men, 9 women, and 26 ± 5 years old) and 16 patients with malocclusions needing orthodontic treatment (5 men, 11 women, and 26 ± 4 years old) participated. Glucose concentration was measured after 5-, 10-, and 15-s mastication of gummy jelly and compared to Hue values obtained from the color-changing gum method (reference method). In addition, all participants were asked to fill out the Oral Health Impact Profile questionnaire (OHIP) to assess differences in perception related to the mouth before and after the placement of braces.

Results: Glucose concentrations were strongly correlated to measures of the two-color chewing gum methods ($R^2 = 0.965$). Both the glucose extraction and chewing gum hue value were the smallest for 5 s chewing cycles and increased as the number of chewing strokes increased for the 15 s chewing cycles. (Hue: $R^2 = 0.510$, $p < 0.001$; glucose: $R^2 = 0.711$, $p < 0.001$) Masticatory efficiency assessed by both methods was significantly lower in orthodontic patients compared to controls ($p < 0.05$), even though it was not affected by bonding ($p > 0.09$). In addition, OHIP scores in physical pain dimension and psychological disability were higher in orthodontic patients than in the control group ($p < 0.005$).

Conclusion: Measurement of glucose concentration was confirmed as a reliable and convenient method for assessing masticatory efficiency. Furthermore, it appears that this method is applicable to patients with braces whose perception in the oral cavity could change.

KEYWORDS
chewing gum, glucose, malocclusion, mastication, quality of life

1 | INTRODUCTION

Occlusion is the relationship of the maxillary and mandibular teeth in a functional contact, whereas malocclusion is the state of deviation from the normal or ideal occlusion.[1] According to the World Health Organization, malocclusion is an anomaly that causes disfigurement or impedes function and requires treatment if the disfigurement or functional defect is likely to be an obstacle to the patient's physical or emotional health well-being.[2] World Dental Federation (FDI) defines malocclusion as the irregularity of the teeth or a mal-relationship of the dental arches beyond the range of what is accepted as normal.[3] Although malocclusion itself is neither a disease nor a life-threatening condition, the demand for orthodontic care has long been growing because malocclusion may impair masticatory function, especially related to reduced occlusal contacts area.[4] As teeth are important for the breakdown and transformation of food particles, malocclusion could be associated with impaired measures of masticatory performance.[5,6] Simply observing the number of chewing cycles required to break down a bolus of food for swallowing can be seen in the presence of malocclusion and reduced occlusal contacts and may be interpreted as decreased masticatory efficiency.[7,8]Despite the potential impact of malocclusion on masticatory function, people often undergo orthodontic treatment because of the aesthetic impairment associated with malocclusion rather than the anatomical irregularities or to prevent the destruction of hard and soft tissues within the oral cavity.[6] Thus, malocclusion and orthodontic care are quality-of-life (QoL) issues.[9] Many studies and clinical observations have shown that the insertion of initial arch wires for levelling and alignment can cause discomfort and pain with individual variation.[10] The process of placing braces on teeth is called bonding. Pain and discomfort during orthodontic treatment may impact patients' QoL.[11,12] However, the influence of pain and discomfort caused by orthodontic appliances on masticatory performance remains unknown.[13]To determine masticatory efficiency in healthy individuals, different methods can be applied.[7,14–16] Measurement of glucose extraction from chewing gummy jelly has been suggested as a convenient method for assessing masticatory function.[17] The glucose concentration method can help evaluate masticatory performance quickly in any setup with minimal equipment.[18–20] Glucose extraction after chewing gummy jelly has been standardised from previous studies and accepted for its ease and hygiene.[19] Colour-changeable chewing gum has been evaluated as a valid and reliable method for evaluating masticatory function.[21] However, a comparison of the glucose concentration method to a proven, validated method like the colour-changing gum has not been previously performed.The aims of this study were to (1) assess the validity of the glucose concentration method in healthy controls in comparison to the two-coloured chewing gum method and (2) to evaluate if the glucose concentration method can be applicable in patients undergoing orthodontic treatment. We hypothesised (1) that there would be a strong correlation between the glucose concentration and two-coloured chewing gum methods, (2) that measures of masticatory efficiency would be decreased in patients during orthodontic treatment compared to matched healthy individuals and (3) that the immediate effects of bonding would be reflected both in the self-reported measures of oral health and masticatory efficiency.

2 | MATERIAL AND METHODS

2.1 | Participants

Sixteen patients (7 men and 9 women, average age ± standard deviation (SD): 26 ± 5 years old) in orthodontic treatment, as well as 16 healthy age-matched healthy controls (5 men and 11 women, average age ± SD: 26 ± 4 years old), participated in this study. The sample size was calculated with a risk of type I and type II errors of 5% and 20%, respectively, and an estimate of the interindividual variation of 25% and a minimal relevant difference to detect as 25%. Thus, a total of 16 participants per group were included. The patients were randomly selected among patients seeking treatment at the Section for Orthodontics at the postgraduate/undergraduate clinic at the Department of Dentistry and Oral Health, Aarhus University, Denmark. Inclusion criteria for patients were ≥18 of age and in orthodontic treatment without tooth extractions. The malocclusion diagnosis for these patients was one of the following: Angle class I with crowding (n = 8), Angle class II, division 1 (n = 5) and division 2 (n = 3). Patients needing orthodontic treatment with tooth extractions were excluded from the study. The patient group was in active treatment at the Section for Orthodontics, Department of Dentistry and Oral Health, Aarhus University. Healthy controls were recruited by advertising in flyers posted on the campus of Aarhus University. Inclusion criteria for healthy controls were ≥18 of age, no previous orthodontic treatment, and having at least 28 natural teeth, no history of medication or analgesics.The fixed appliance installation consists of placing brackets on the teeth with dental adhesive and introducing the first arch wire. This will be called bonding or bonding of braces throughout the study.The study was conducted in accordance with the Helsinki Declaration II and was approved by the Central Denmark Region ethics committee (approval No.1-10-72-14-18, Aarhus County, Denmark). Unrestricted information was given individually to all participants before the experiment. In addition, the National Scientific Committees' pre-printed pamphlet 'Experimental Rights in a Health Science Research Project' was distributed together with written information about the project.

2.2 | Study design

All participants had a standard clinical examination with inspection of the oral mucosa and palate, gingiva and periodontium, dental status and occlusion. Masticatory efficiency was assessed with the two methods; colour-changing chewing gum and glucose extraction from gummy candy. The two tests were conducted once in healthy

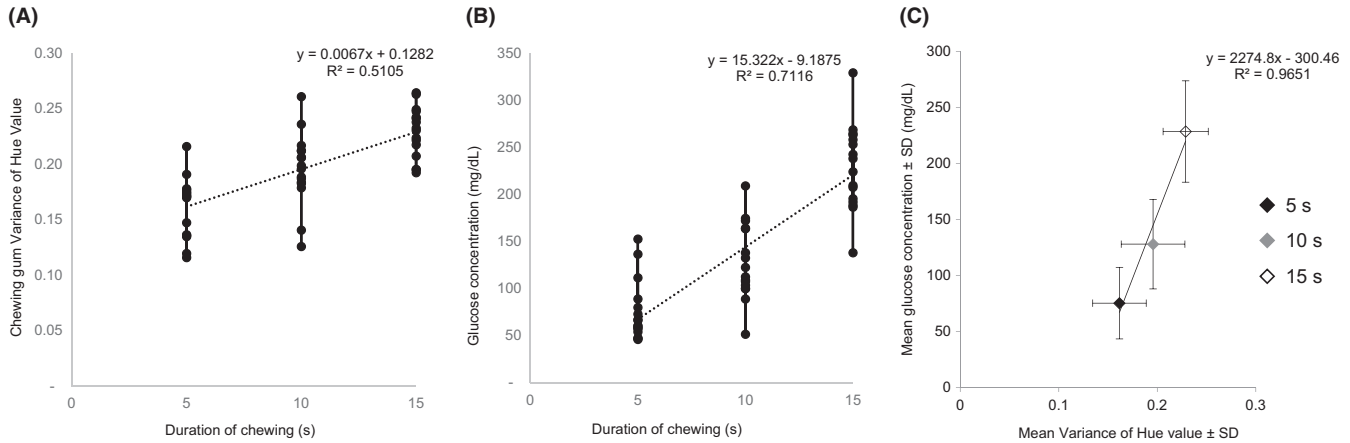

FIGURE 1 (A) Coefficient of correlation between Chewing gum variance of hue value with duration of chewing at three time points 5, 10 and 15 s. $N = 16$. (B) Coefficient of correlation between value of glucose concentration method (mg/dl) with duration of chewing at three time points 5, 10 and 15 s. $N = 16$. (C) Coefficient of correlation between Mean value ± Standard deviation (SD) of glucose concentration method and the variance of hue value of chewing gum for healthy controls. $N = 16$.

controls and twice on the same day in patients in orthodontic treatment: once before bonding fixed appliances and after bonding (within 2 h).

2.3 | Glucosensor

The same operator asked all participants to chew a standardised gummy tablet (cylindrical shape, 10 mm diameter and 10 mm height) freely for 5, 10 and 15 s. Then, each participant was asked to spit out the gummy tablet's chewed pieces into a beaker with a sieve whose size was 1.0 × 1.0 mm. After that, 5 ml of water was given to rinse the oral cavity, and each participant was asked to spit into the same beaker. Three samples were collected from each participant, and the procedure was repeated twice. Finally, each sample was mixed, and a drop was placed on the glucose monitor's measurement chip (Glucosensor tips, GC Japan). A measuring device (Glucosensor GS-II, GC. Japan) thus detected the glucose levels of all participants.

2.4 | Chewing gum method

All participants were asked by the same operator to chew a colour-changing gum (Lotte, Xylitol) for three different chewing cycles; 5, 10 and 15 s. The gum was made to change its colour from green to red as chewing progress because the yellow and blue dyes seep into saliva, and the red colour appears because of citric acid elution.[21] After each chewing cycle, the participants were asked to spit the gum on a cellophane sheet. The chewed gum was flattened to a thickness of 1.5 mm in polyethylene films by compression between two glass plates and was scanned on both sides using a flatbed scanner. Each scanned image was then saved and assessed with a freely available program called View gum software.All images were imported into this View-gum software and processed as follows: Each pair of images (front and back) was scanned and then assembled into one composite image in the vertical or horizontal direction described in previous studies using this software.[21,22] With increasing degrees of colour mixing, each colour group's two hue peaks converge and eventually fuse at an intermediate position into one peak when the colours are perfectly mixed. The variance of the hue (VOH) is to be considered a measure of mixing and serves as an estimate of the masticatory performance.

2.5 | Questionnaires

The Oral Health Impact Profile questionnaire (OHIP; number of items 49) was used for the assessment of oral health-related QoL,[23,24] the McGill Pain Questionnaire (MPQ) for semi-quantitative measurement of pain and discomfort[25,26] and the Jaw Functional Limitation Scale (JFLS) to assess jaw function disability[27] as a part of the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD).[28] Each participant was asked to fill out these questionnaires after the bonding of orthodontic appliances.

2.6 | Statistics

Statistical analyses were performed using StataIC 16 and Prism 8 software. The coefficient of correlation between the value of the glucose concentration method and the VOH value of chewing gum was calculated for each group. The average value and standard deviation of the glucose concentration method and VOH value were calculated for all participants. A one-way ANOVA was performed on healthy and patient group. Furthermore, post-hoc Tukey's honestly significant difference test with corrections for multiple comparisons was performed. All data are presented as mean ± SEM. The significant level was set at $p < .05$. The results from the questionnaires were calculated in accordance with DC/TMD Self-report Instrument

Scoring Manual.[28] JFLS 20 was calculated for each subcategory as a sum of items. OHIP 49 was calculated with respective weights along with mean and standard deviation for all participants. The MPQ questionnaire was recorded as the most commonly used words to describe any painful or unpleasant sensation evoked by the bonding.

3 | RESULTS

3.1 | Comparison of methods for masticatory efficiency in the control group

Hue variation decreased, and hue values increased significantly with an increasing number of chewing cycles, indicating a higher degree of colour mixture. Both the glucose extraction and chewing gum variance of hue (VOH) value were the smallest for 5 s chewing cycles and increased as the number of chewing strokes increased for the 15 s chewing cycles. (Hue: R^2 =0.510, p <.001; glucose: R^2 =0.711, p <.001; Figure 1A,B)The coefficient of correlation between the two methods was highly significant for all healthy controls (Hue with glucose R^2 =0.965; Figure 1C).

3.2 | Comparison of masticatory efficiency between groups

The one-way ANOVA showed a significant effect of groups on glucose concentration (p <.001, F = 10.13). Furthermore, a post-hoc test showed that, regardless of the presence of fixed appliances, glucose concentrations after 15 s of chewing in patients were significantly lower compared to healthy controls (before: p <.001, after: p =.005; Figure 2A). Bonding of braces did not significantly influence glucose concentration in patients (p =.619). The one-way ANOVA also showed that groups showed a significant effect on VOH values (p <.001, F = 38.81). Similar to glucose concentration, VOH values after 15 s of chewing in patients were significantly lower compared to healthy controls (both before and after: p <.001), There was also significant difference in VOH values before and after bonding. (p =.235; Figure 2B).

3.3 | Questionnaire findings

The JFLS scores in all subcategories between healthy participants and patients were not significantly different (p >.084; Table 1).The OHIP 49 values were significant in orthodontic patients in physical pain (p = .001), psychological disability (p = .005) and handicap (p = .045) when compared to the matched control group (Table 2). The MPQ Questionnaire indicated that bonding in orthodontic patients was described as pressing (5/16), beating (4/16), sharp (4/16), aching (4/16), pricking (3/16) and tiring (2/16) and annoying (5/16).

4 | DISCUSSION

A strong correlation between the glucose concentration method and the two-colour chewing gum method was confirmed, which indicates the validity of the glucose concentration method in assessing masticatory efficiency. Furthermore, masticatory efficiency was lower in patients in orthodontic treatment using both methods. Even though it did not affect masticatory efficiency, bonding was associated with reports of unpleasant sensations. Our findings also suggest that masticatory efficiency can be conveniently assessed with the glucose concentration method in the clinic and used together with self-report measures (JFLS and OHIP) to follow patients in orthodontic treatment.Previous studies assessing masticatory efficiency in different kinds of dentition have been valuable to establish its reliability for clinical usage compared with other methods to assess chewing.[24] The chewing gum method has been a gold standard that has been previously used and accepted in evaluating masticatory efficiency.[21] Therefore, to assess the reliability

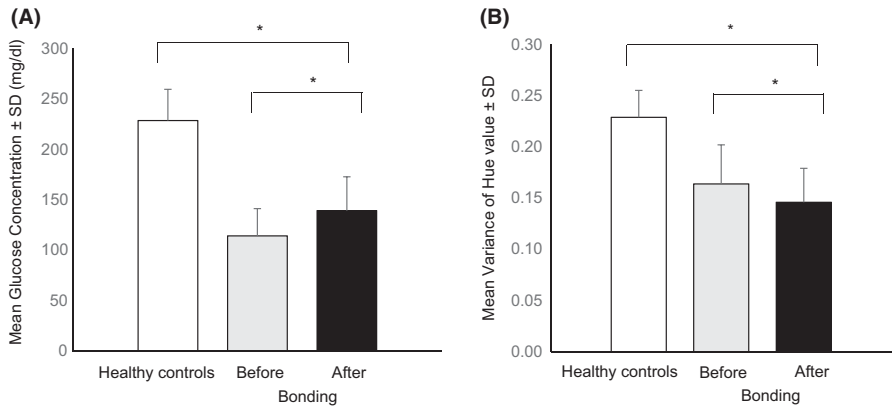

FIGURE 2 (A) Average value ± Standard deviation (SD) of glucose concentration method of healthy controls (N = 16), patients before and after bonding of braces (N = 16). *Shows that statistical significance between healthy, before and after bonding of braces. (B) Average value ± Standard deviation (SD) of Chewing gum variance of hue value of healthy controls (N = 16) and patients before and after bonding of braces (N = 16). *Shows that statistical significance between healthy, before and after bonding of braces.

TABLE 1 Mean scores (±SD) for each category in the Jaw Functional Limitation Scale

Jaw Functional Limitation Scale	Patients	Healthy participants	*T*-test
Mastication	0.29 ±0.97	0.13 ±0.34	NS
Mobility	0.15 ±0.51	0.03 ±0.18	NS
Verbal and non-verbal communication	0.08 ±0.45	0.06 ±0.30	NS

Note: Number of patients ($N = 16$).
Abbreviation: NS, not significant.

TABLE 2 Mean scores (±SD) for each dimension with respective weights in oral health impact profile 49(OHIP 49)

Oral health impact profile	Patients	Healthy participants	*T*-test
Functional limitation	1.52 ±1.03	1.25 ±0.22	NS
Physical pain	7.82 ±3.40	2.33 ±0.97	0.001[a]
Psychological discomfort	6.90 ±0.30	3.45 ±0.15	NS
Physical disability	3.48 ±0.36	1.52 ±0.56	NS
Psychological disability	4.80 ±2.40	1.30 ±0.50	0.005[a]
Social disability	2.36 ±1.98	0.62 ±0.62	NS
Handicap	1.48 ±1.48	0 ±0	0.045[a]

Note: Number of patients ($N = 16$).
Abbreviation: NS, not significant.
[a]Shows statistically significant values.

and validity of the glucose concentration method, we compared it to this validated chewing gum method.[21,22] In the glucose concentration method, the amount of released glucose during chewing is directly associated with the degree to which the glucose substance has been fragmented and masticatory performance.The chewing gum method has been compared with other methodologies,[29,30] yet this study is the first to compare it with the glucose concentration method. The linear relationships between the two methods in this study suggest that the glucose concentration method is a robust and reliable method to evaluate masticatory efficiency. The easy applicability of this method makes it the right candidate for clinical studies and, in particular, assessing masticatory efficiency in clinical settings. On the other hand, the colour-changing gum evaluation needed for this method requires special equipment to analyse colour of chewed gum, thus making it slightly more difficult in daily clinical usage.[21,29,31]After establishing viability of the glucose concentration method, we applied it clinically to patients starting orthodontic treatment. In this study, masticatory efficiency was measured before the placement of braces and a few hours after bonding braces on the same day. Literature shows that masticatory efficiency is reduced during the first 24–48 h of fixed appliance installation and activation and later normalised.[32,33] Immediate and delayed responses are induced during levelling and alignment of the teeth by orthodontic forces from the dentoalveolar structures. Immediate responses usually occur after placing the arch wires. Therefore, assessment of the application of both tests during this period was performed in this study.[34,35]

A previous study showed that even experimental pain in the masseter muscle experimentally caused by glutamate injection did not affect the masticatory efficiency,[36] which is consistent with our findings showing that bonding of braces did not affect masticatory efficiency. The results of our study suggest that the glucose concentration method allowed immediate assessment of the masticatory efficiency at the chairside despite the patient's discomfort at the onset of treatment. Bonding only affected self-reported assessment, even though the objective evaluation of masticatory efficiency was unchanged at this stage. However, further testing is needed to assess if masticatory efficiency stays unaffected after the orthodontic treatment. Indeed, initial levelling does cause some mobility of teeth; thus, masticatory efficiency could be affected later during and after treatment.[18,37–39] Based on research that reports a lack of adequate emphasis on pain communication and management in orthodontic training, it has been predicted that there could be some inconsistencies between patients' and treatment providers' pain assessments.[39–42]

Currently, the most significant emphasis is placed on the functional outcome of orthodontic treatment. However, a recent study assessing orthodontic outcomes found that patients might rank results differently than what clinicians would do.[43]Indeed, the term health-related quality of life has been used to describe an individual's assessment of one's well-being is affected by the following factors: the experience of pain/discomfort, physical function, psychology (i.e., concerning the person's appearance and self-esteem) and social function such as interactions with others.[10,11,13,44,45] The result in this study showed that the patients experienced a significant amount of pain after bonding of braces and placement of initial wires. While such pain is unlikely to be unavoidable after orthodontic treatment,[46] it could be beneficial to make sure that the patients are prepared and informed about such treatment-related pain sensations and alleviate pain by prescription of analgesic medication after the treatment.

4.1 | Methodological limitations of the study

Shortcomings of our findings are related to further assessment and the population. For further analysis, the patients in orthodontic treatment could be given a second set of questionnaires. The tests could be repeated at the second appointment after the initial alignment phase, like 3 months after the start of treatment and again after completing treatment and removal of fixed appliances in the retention phase. We consider our study as the first phase of evaluating masticatory efficiency tests using the glucose concentration method in patients with malocclusion. To understand the comprehensive picture, further assessment of the included patients during treatment and after achieving a better occlusion

with orthodontic treatment will help understand malocclusion's relation to masticatory efficiency. The other sample that can be evaluated are patients needing orthognathic surgery. The tests and questionnaires can be assessed pre and post-surgical in these patients.

5 | CONCLUSION

This study suggests that the glucose concentration method is an effective and reliable indicator of masticatory efficiency. Orthodontic patients can be ideal candidates for assessing masticatory efficiency during treatment using our more straightforward chairside method. Patients should be well informed about psychological discomfort like pain that can arise throughout the treatment. Further studies are required to assess the pain and changes in masticatory efficiency in patients in orthodontic treatment.

AUTHOR CONTRIBUTIONS

Akila Aiyar involved in formal analysis, investigation, validation, methodology, writing the original draft and visualisation. Akiko Shimada involved in conceptualisation, methodology, validation, formal analysis, reviewing and editing and visualisation. Peter Svensson involved in conceptualisation, methodology, validation, reviewing and editing and supervision.

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CONFLICT OF INTEREST

None.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available at Section of orthodontics and Section for Orofacial pain and Jaw function, Aarhus University as per guidelines from National Science Ethics Committee, Denmark. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from the authors with permission from National Science Ethics Committee, Denmark.

PEER REVIEW

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