

Original Article

Reliability and validity of a quantitative color scale to evaluate masticatory performance using color-changeable chewing gum

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In the present study, we developed a novel color scale for visual assessment, conforming to theoretical color changes of a gum, to evaluate masticatory performance; moreover, we investigated the reliability and validity of this evaluation method using the color scale. Ten participants (aged 26–30 years) with natural dentition chewed the gum at several chewing strokes. Changes in color were measured using a colorimeter, and then, linear regression expressions that represented changes in gum color were derived. The color scale was developed using these regression expressions. Thirty-two chewed gums were evaluated using colorimeter and were assessed three times using the color scale by six dentists aged 25–27 (mean, 25.8) years, six preclinical dental students aged 21–23 (mean, 22.2) years, and six elderly individuals aged 68–84 (mean, 74.0) years. The intrarater and interrater reliability of evaluations was assessed using intraclass correlation coefficients. Validity of the method compared with a colorimeter was assessed using Spearman's rank correlation coefficient. All intraclass correlation coefficients were >0.90, and Spearman's rank-correlation coefficients were >0.95 in all groups. These results indicated that the evaluation method of the

color-changeable chewing gum using the newly developed color scale is reliable and valid.

Key words: Mastication, Color, Reproducibility of Results, Validation Studies, Chewing gum

Introduction

Specialists in dentistry and individuals involved in healthcare and education have become increasingly aware of the importance of mastication^{1,2}. Therefore, masticatory performance requires simple and effective evaluation methods that practical for use. Masticatory performance has often been evaluated by measurement of an individual's ability to grind or pulverize a test food by chewing. The degree of food breakdown is then determined by sieving³⁻⁵. Another popular method evaluates the individual's ability to mix and knead a food bolus. Also, two-color chewing gum⁶⁻⁹ and paraffin wax¹⁰⁻¹³ have been used as test items for the quantification of mixing ability.

We have used a gum that changes color as chewing proceeds for simple and effective evaluation¹⁴⁻¹⁶. Masticatory performance can be evaluated only by the measurement of changes in the gum color. Chewing gum has advantages as a test process because it simulates natural and stable chewing¹⁷. The gum that we designed was factory-produced and individually packaged, which ensured consistent quality.

We used two methods for measuring changes in gum color: One is a colorimeter and the other is a dedicated color scale¹⁵. Because the former is more accurate but needs special equipment, it is better suited for use at research institutions. The latter is easier and requires only a paper color scale, which would allow anyone to

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evaluate masticatory performance at any place. However, the color scale that we developed comprised colors selected only by visual inspection and did not conform to actual color changes. Therefore, we need to redevelop a more accurate color scale according to theoretical color analyses.

Reliability and validity must be established when a new evaluation method is developed¹⁸. Reliability, that is, precision or reproducibility, is defined as the degree to which two values are consistent with each other when measurements are recorded repeatedly. Validity is defined as the degree to which a variable is actually consistent with what it is intended to measure.

The present study developed a novel color scale that conformed to theoretical color analyses and proved the reliability and validity for the establishment of evaluation methods using color scales.

Materials and Methods

Color measurement of test items

The test chewing gum (70 × 20 × 1 mm, 3.0 g) contained xylitol, citric acid, and red, yellow, and blue dyes that change color when chewed (Masticatory Performance Evaluating Gum XYLITOL, Lotte Co. Ltd., Tokyo, Japan). The red dye is pH-sensitive and changes color under neutral or alkaline conditions. Because citric acid maintains a low internal pH, the gum is yellowish-green before being chewed. The gum changes to red as chewing progresses because the yellow and blue dyes seep into saliva, and red color appears as a result of citric acid elution.

Measurement of color change using colorimeter

Color was measured immediately after the gum was chewed. Changes in color were visualized as three-dimensional coordinates organized along L*, a* and b* axes using the CIELAB color system defined by the International Commission on Illumination: L* represents the lightness of the color, a* represents the degree of color between red and green, and b* represents the degree of color between yellow and blue. Positive values for a* and b* indicate red and yellow, respectively. The chewed gum was flattened to a thickness of 1.5 mm in polyethylene films by compression between two glass plates and measured using a colorimeter (CR-13; Konica Minolta Sensing, Tokyo, Japan) positioned at center, about 3 mm above, below, and to the right and left of the center of the films. For L*, a*, and b*, mean values for the five points were determined. Thereafter, mean differences between two

colors in the CIELAB color space (ΔE) were calculated before and after chewing using the following equation, in which the measured L*, a*, and b* values before chewing were 72.3, -14.9, and 33.0, respectively:

$$\Delta E = \sqrt{(L^* - 72.3)^2 + (a^* + 14.9)^2 + (b^* - 33.0)^2}$$

ΔE value means color changes before and after chewing and can be used as evaluation value of masticatory performance.

Development of color scale

Ten participants (male, 70%), aged 26–30 (mean, 27.7) years, with natural dentition without missing teeth, except for third molars, participated in this study. Participants with caries, severe periodontal disease, and clinical signs or symptoms of temporomandibular disorders and salivary dysfunction were excluded. They chewed the gum for 20, 40, 60, 80, 100, 120, 160, and 200 strokes five times repeatedly with rest for at least 5 min between chewing tasks. One examiner measured color changes in the chewed gums and calculated ΔE values as described above. Thereafter, linear regression expressions of ΔE and L*, a*, and b* values were derived.

The color scale was developed as follows: A text book of colorimetric says two colors which are more than six apart in ΔE are considered a distinctly-different color¹⁹. Therefore, we set the interval of ΔE between adjacent colors to seven, the ΔE value of the first color to 0, and the last to 70. Each color was detected by the conversion of the L*, a*, and b* values from ΔE values of the color using these linear regression expressions of ΔE and L*, a*, and b* values.

Reliability and validity of the color scale

Six dentists aged 25–27 (mean, 25.8) years, six preclinical dental students aged 21–23 (mean, 22.2) years, and six elderly individuals aged 68–84 (mean, 74.0) years were recruited from among dentists and students of Tokyo Medical and Dental University and patients who attended the prosthodontics clinic at the university dental hospital. Participants with color blindness as per the results of the Ishihara color blindness test²⁰ were excluded.

Reliability and criterion validity of the evaluation method with the color scale were assessed using 32 chewed gums. ΔE values of the chewing gums were calculated using colorimeter for even distribution from 10 to 70. A random-order evaluation of the 32 samples using the color scale was grouped as a single cycle, and each participant performed three continuous

cycles. Participants were only instructed to select quickly the most similar color from the color scale compared with each sample. The samples were placed in a freezer except assessing time not to change the color by chemical reaction progression.

The Ethics Committee at the Tokyo Medical and Dental University approved the study protocol (#303), which conformed to principles described in the World Medical Association Declaration of Helsinki (2002), and all participants provided written, informed consent before enrollment in the study.

Statistical analysis

We used the ΔE value of selected color as evaluation value of color scale method. Reliability was assessed using intraclass correlation coefficients (ICCs) for intrarater and interrater consistency. Validity was assessed using Spearman's rank correlation coefficient between the new method using the color scale and the conventional method using a colorimeter. Statistical analyses were performed using SPSS statistics 17.0 (SPSS Japan Inc., Tokyo, Japan). P values <0.05 were considered significant for all statistical analyses.

Results

Figure 1 indicates that relationships were significantly and highly linear between ΔE and L^* , a^* , and b^* . The linear regression expression for each of these was as follows:

$$L^* = -0.32\Delta E + 72.57 \quad (R^2 = 0.92, P < 0.001)$$

$$a^* = 0.75\Delta E - 14.59 \quad (R^2 = 0.99, P < 0.001)$$

$$b^* = -0.59\Delta E + 33.51 \quad (R^2 = 0.98, P < 0.001)$$

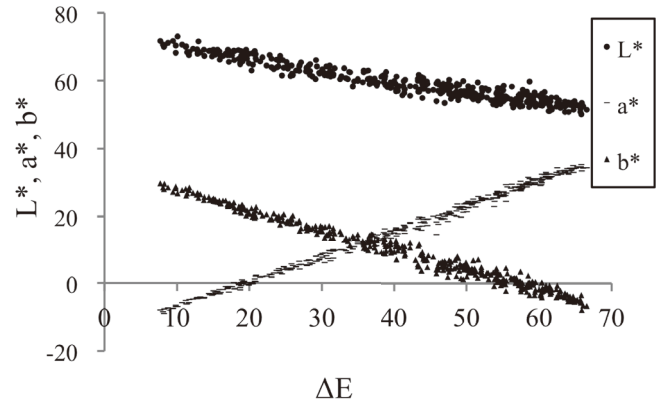


Figure 1. Relationships between ΔE and L^* , a^* , and b^*

ΔE and L^* , a^* , and b^* are significantly and highly related. Corresponding linear regression expressions are as follows: $L^* = -0.32\Delta E + 72.57$ ($R^2 = 0.92, P < 0.001$); $a^* = 0.75\Delta E - 14.59$ ($R^2 = 0.99, P < 0.001$); $b^* = -0.59\Delta E + 33.51$ ($R^2 = 0.98, P < 0.001$).

Figure 2 presents the new color scale that was developed using the regression expression.

Table 1 displays ICCs of intrarater and interrater consistency. ICCs in all participants or groups were >0.90 .

Spearman's rank correlation coefficients between ΔE values measured using the color scale and the colorimeter were significant in all groups (dentists, $r_s = 0.96, P < 0.001$; students, $r_s = 0.97, P < 0.001$; elderly,

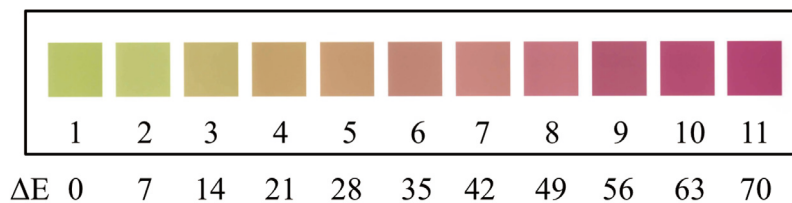


Figure 2. Color scale

Conversions of ΔE into L^* , a^* , and b^* values using linear regression.

ΔE values of first and last colors set to 0 and 70, respectively, and interval of ΔE values between adjacent colors is 7. The numbers under each color are response alternatives using color scale.

Table 1. Intraclass correlation coefficients for each group of examiners.

| Group | Dentists | Students | Elderly | All groups |
|------------------------|------------------|------------------|------------------|------------|
| Intrarater consistency | 0.96, 0.97, 0.93 | 0.98, 0.95, 0.96 | 0.96, 0.94, 0.98 | |
| | 0.96, 0.95, 0.92 | 0.98, 0.96, 0.98 | 0.96, 0.97, 0.94 | |
| Interrater consistency | 0.93 | 0.96 | 0.92 | 0.94 |

$r_s = 0.96$, $P < 0.001$). Figure 3 presents the correlation between both methods.

Discussion

In the present study, we developed a novel color scale for visual assessment of the gum to evaluate masticatory performance. Visual evaluation needs the same appearance indicates the same level of performance. The highly linear relationships between ΔE and L^* , a^* , and b^* shown in Figure 1 mean that gums with the same ΔE values have the same L^* , a^* , and b^* value and, therefore, are visually the same color. This fact indicates the possibility of visual evaluation using a dedicated color scale.

Because color values of our new color scale were calculated using the linear regression expressions, they conformed to actual color changes in theory. We analyzed the reliability and validity of the evaluation method using the color scale to investigate color values, practically conforming to the changes. The reliability and validity were assessed among dentists, preclinical dental students, and elderly individuals. Because the method can be used by individuals other than specialists, we regarded dental students as examples of the general population. Studies in ophthalmology have reported that the density of the human lens changes with age, particularly in those over 60 years of age²¹, and therefore, we included the elderly in the present study as well.

For accurate determination of reliability, participants were to be prevented from remembering their previous evaluation value of each sample²². Because we considered that remembering evaluations of 32 samples would be impossible, participants were requested to perform all evaluation cycles without intervening rest periods. Intrarater consistency is the degree of coincidence among values repeatedly assessed by a single participant. Interrater consistency is the degree of coincidence among values between participants within each group. Several studies have assessed reliability using intraclass correlations (ICCs)²³⁻²⁵. As a general rule, ICCs >0.80 are considered "almost perfect"²⁶. ICCs in this study for intrarater and interrater consistency for the values of a participant or a group were >0.90 , indicating that the evaluation method using the color scale is reliable as per the general rule.

The validity evaluated in this study is called "criterion validity," the correlation of a new scale with some other measurement, ideally, a gold standard, which has been used and accepted in the field. We determined ΔE measured using a colorimeter as the standard because the colorimeter is accepted as a color measurement

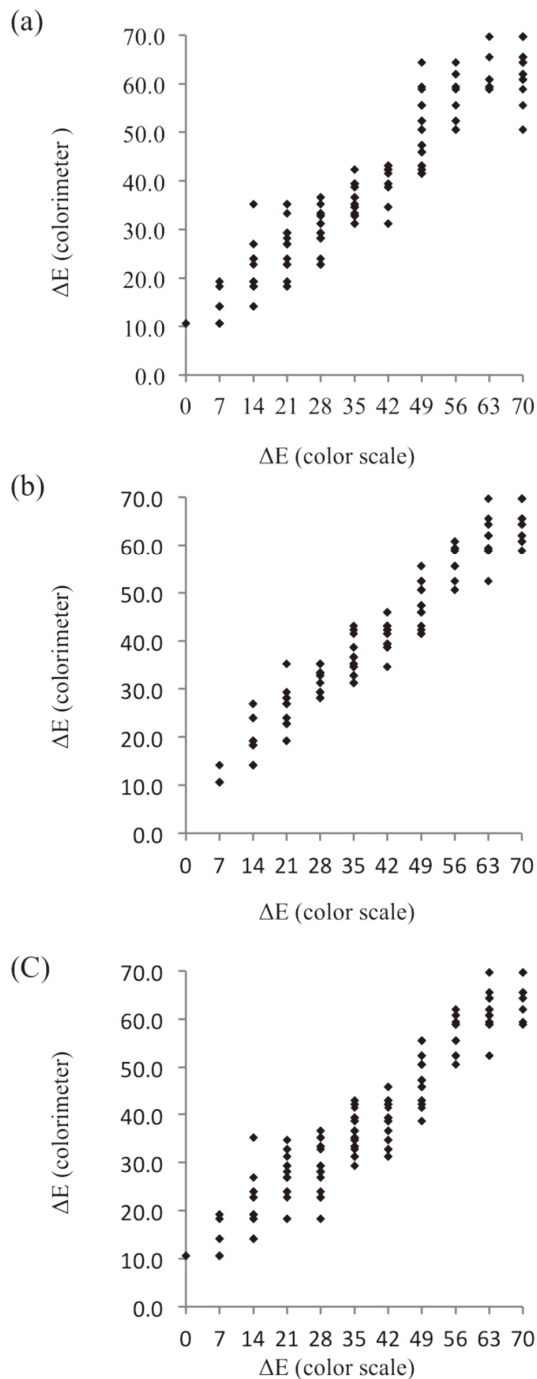


Figure 3. Correlation between ΔE values measured using the color scale and colorimetry

The ΔE value of selected color was used as evaluation value of color scale method.

(a) Dentists ($r_s = 0.96$, $P < 0.001$), (b) students ($r_s = 0.98$, $P < 0.001$), and (c) elderly ($r_s = 0.96$, $P < 0.001$). Methods significantly correlate in each group.

technique. Spearman's rank correlation coefficients between the new method with the color scale and the accepted method with a colorimeter were significantly high in each group, thereby proving the validity criterion for evaluation using the color scale (Figure 3).

In the present study, we analyzed reliability and validity when samples were distributed in all color gums could be, and in this case our chewing gum method has high reliability and validity. However the analyses of reliability and validity using ICCs and correlation coefficients, which are influenced by the distribution of samples, have a limitation. In this study the wider distribution of samples might lead to the higher ICCs and correlation coefficients. To overcome this limitation, we need to perform the same experiments in which the samples are gums chewed in the same situation as actual use.

The present study developed a new color scale that conformed to theoretical color analyses, and evaluation using this color scale was proved to be reliable and valid. We believe that the method will be useful for evaluating masticatory performance at any place and in wide-ranging surveys. To further improve our method, we plan to investigate the detectability of our chewing gum method in various types of dental statuses.

Conflict of interest

This study was partially supported by Lotte Co., Ltd., Tokyo, Japan. The authors report no potential conflicts of interest for this study.

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