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【 ORIGINAL ARTICLE 】

Screening for a Decreased Masticatory Function by a Color-changeable Chewing Gum Test in Patients with Metabolic Disease

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Abstract:

Objective This study aimed to reveal the screening performance of a color-changeable chewing gum test for a decreased masticatory function in the assessment of oral hypofunction in patients with metabolic diseases.

Methods We analyzed 1,000 patients with metabolic diseases, including diabetes, dyslipidemia, hypertension, and hyperuricemia. A decreased masticatory function was diagnosed by a gummy jelly test. Patients were asked to chew a test gum, which changed from green to red by thorough mastication, 60 times for 1 minute. The color change was visually evaluated using the color scale, from 1 (green-dominant) to 10 points (red-dominant), and was colorimetrically quantified as delta E in the L*a*b* color space. The screening performance for a decreased masticatory function was evaluated with the receiver operating characteristic (ROC) curve.

Results Seventy-seven patients (7.7%) were diagnosed with a decreased masticatory function. The mean color scale and delta E of the gum test were 6.7±1.8 points and 42.9±6.7 units, respectively. The area under the ROC curve was 0.822 (95% confidence interval, 0.768-0.872) for the color scale and 0.838 (0.781-0.890) for delta E (p=0.41). The optimal cut-off point of the color scale was 5.5 (5.0-6.5) points, whereas that of delta E was 37.7 (35.5-38.8) units. The optimal cut-off points were not significantly different between the subgroups divided by clinical characteristics.

Conclusions A color-changeable chewing gum test using the color scale as well as delta E would be a useful tool for screening patients with metabolic diseases for a decreased masticatory function in the assessment of oral hypofunction.

Key words: metabolic disease, masticatory function, color-changeable chewing gum test, screening performance

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Introduction

A decreased masticatory function increases the risk of physical frailty (1, 2) and has attracted increasing attention in healthcare settings (3). In Japan, the examination and management of oral hypofunction in dental practice has been accordingly covered by national health insurance since 2018 (4).

Patients with metabolic diseases, especially diabetes mellitus, are at high risk of periodontitis (5, 6), which induces tooth loosening and loss, eventually impairing the masticatory performance. Patients with a decreased masticatory function are apt to favor soft foods over hard-to-chew ones, causing their diet to become unbalanced (7-9), which will reduce the control of their metabolic disease (10-13), poten-

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tially creating a vicious cycle. It is therefore of clinical importance to evaluate the masticatory function in patients with metabolic diseases.

In the assessment of oral hypofunction, a decreased masticatory function is currently diagnosed by a gummy jelly test (3), but the test is not always easy to perform in clinical settings. Recently, a color-changeable chewing gum test was developed (14). The test gum changes from green to red by thorough mastication (14). Masticatory performance can be quantitatively measured by checking the color of the gum. The test is easy to perform and thus has been widely used for the quantitative measurement of the masticatory function in both clinical and epidemiological studies (15-20). However, the optimal cut-off point for a decreased masticatory performance in the assessment of oral hypofunction remains unclear.

The present study assessed the screening performance of a color-changeable chewing gum test for a decreased masticatory function in patients with metabolic diseases.

Materials and Methods

Study population

We analyzed a clinical database of the study of CHEWING ability in patients with LIFEstyle disease (CHEWING-LIFE study), a cross-sectional study enrolling 1,000 Japanese patients with metabolic diseases at Shiraiwa Medical Clinic, Kashiwara City, Osaka, Japan, between November 2019 and March 2020. The inclusion criteria of the CHEWING-LIFE study were 1) ≥20 years of age and 2) receiving treatment at the clinic for ≥1 of the following metabolic diseases: diabetes mellitus, dyslipidemia, hypertension, and hyperuricemia. The exclusion criteria were 1) mentally disabled persons who had difficulty giving informed consent by themselves and 2) those who were expected to have difficulty undergoing study examinations.

The study was performed in accordance with the Declaration of Helsinki and was approved by the ethics committees of Osaka University Hospital. Written informed consent was obtained from every participant.

Definitions

The body mass index (BMI) was calculated as the body weight in kilograms divided by the square of the height in meters. Obesity was defined as the BMI ≥25 kg/m^2, according to the domestic criteria (21). A decline in gait speed (slowness) was determined as a 5-m gait speed <1.0 m/s, whereas a decline in handgrip strength (weakness) was determined as a handgrip strength <26 kg in men or <18 kg in women (22). Whether or not participants felt difficulty eating hard food was surveyed as a subjective complaint by a questionnaire. An oral moisture checker (Mucus; Life, Saitama, Japan) was used to measure mucosal wetness in the central area of the tongue dorsum, and oral dryness was determined when the measured value was less than 27.0 units (3). A decreased masticatory function was diagnosed by a gummy jelly test as recommended (3). In brief, participants were asked to chew a test glucose-containing gummy jelly for 20 seconds without swallowing it and then hold 10 mL of water in their mouth and spit it out together with the jelly. Glucose eluted from the chewed jelly into the water was measured in mg/dL, using a Gluco Sensor GS-II (GC Corporation, Tokyo, Japan). Patients with a glucose level < 100 mg/dL were diagnosed with a decreased masticatory function (3).

Color-changeable chewing gum test

Participants were asked to chew a test gum (Masticatory Performance Evaluating Gum XYLITOL; Lotte, Tokyo, Japan) for one minute, with the chewing rate controlled at once per second by an electronic metronome (23). After chewing 60 times, they spit the gum out, and the color of the gum was visually evaluated using the color scale (Oral Care, Tokyo, Japan), from 1 (green-dominant) to 10 points (red-dominant) (14, 24, 25). If the color of the gum appeared mottled, the average value of the lowest and highest points was determined as the representative value. For example, if the color ranged from 5 to 8 points, the representative value was determined to be (5+8)/2=6.5 points.

The color change of the gum was also evaluated using a colorimeter (CM700d; Konica Minolta Sensing, Tokyo, Japan) (14, 24, 25). The colorimeter measured the color of the gum before and after chewing, based on the L*a*b* color space model defined by the International Commission on Illumination (also called the CIELAB color space model), and the color change was recorded as delta E. In brief, in the L*a*b* model, the L* axis represents the lightness, the a* axis the red/green opponent colors, and the b* axis the yellow/blue opponent colors. Delta E represents the distance between two colors in the L*a*b* three-dimensional color space. The representative value of each participant was determined by averaging the colorimetric measurements at five random points on the gum (24, 25).

Statistical analyses

Data are given as means and standard deviations (SDs) for continuous variables or as frequencies and percentages for discrete variables, if not otherwise mentioned. A p value <0.05 was considered statistically significant, and 95% confidence intervals were reported where appropriate. Differences in clinical characteristics between groups with and without a decreased masticatory function were tested by Welch's *t*-test for continuous variables and by the chi-squared test for dichotomous variables. The screening performance of the color-changeable chewing gum test for a decreased masticatory function was evaluated with the receiver operating characteristic (ROC) curve. The optimal cut-off point was determined based on the Youden index. To check whether or not the clinical characteristics would influence the optimal cut-off point, we divided the study population into subgroups by clinical characteristics and deter-

Table 1. Characteristics of the study population.

	Overall population	Decreased masticatory function		
		Yes	No	p value
n	1,000	77	923	
Age (years)	66±11	70±10	66±11	0.001
Elderly (≥65 years)	590 (59.0%)	54 (70.1%)	536 (58.1%)	0.052
Males	547 (54.7%)	38 (49.4%)	509 (55.1%)	0.39
Smoking history	521 (52.1%)	42 (54.5%)	479 (51.9%)	0.74
Current smoking	160 (30.7%)	14 (33.3%)	146 (30.5%)	0.83
Body mass index (kg/m^2)	23.7±3.8	24.5±4.1	23.6±3.7	0.058
Obesity (≥25 kg/m^2)	305 (30.5%)	33 (42.9%)	272 (29.5%)	0.020
Diabetes mellitus	765 (76.5%)	70 (90.9%)	695 (75.3%)	0.003
Oral antidiabetic agent	620 (81.0%)	53 (75.7%)	567 (81.6%)	0.30
GLP-1 receptor antagonist	69 (9.0%)	8 (11.4%)	61 (8.8%)	0.60
Insulin use	243 (31.8%)	30 (42.9%)	213 (30.6%)	0.050
Dyslipidemia	752 (75.2%)	56 (72.7%)	696 (75.4%)	0.70
Antihyperlipidemic agent	652 (86.7%)	44 (78.6%)	608 (87.4%)	0.097
Hypertension	667 (66.7%)	58 (75.3%)	609 (66.0%)	0.12
Antihypertensive agent	572 (85.8%)	52 (89.7%)	520 (85.4%)	0.49
Hyperuricemia	121 (12.1%)	8 (10.4%)	113 (12.2%)	0.77
Antihyperuricemic agent	100 (82.6%)	7 (87.5%)	93 (82.3%)	1.00
Cardiovascular disease	116 (11.6%)	10 (13.0%)	106 (11.5%)	0.83
Decline in gait speed	165 (16.5%)	23 (29.9%)	142 (15.4%)	0.002
Decline in handgrip strength	143 (14.3%)	22 (28.6%)	121 (13.1%)	<0.001
Denture use	510 (51.1%)	59 (76.6%)	451 (48.9%)	<0.001
(Missing data)	1 (0.1%)	0 (0.0%)	1 (0.1%)	-
Feeling difficulty eating hard food	278 (27.8%)	39 (50.6%)	239 (25.9%)	<0.001
Oral dryness	236 (23.6%)	21 (27.3%)	215 (23.3%)	0.52
Decreased masticatory function	77 (7.7%)	77 (100.0%)	0 (0.0%)	-
Color-changeable chewing gum test				
Color scale	6.7±1.8	4.7±1.5	6.9±1.7	<0.001
Delta E	42.9±6.7	32.5±9.9	43.7±5.6	<0.001

Data are mean±standard deviation, or number (percentage).

mined the subgroup-specific optimal cut-off points. We compared the optimal cut-off points between the subgroups. p values and 95% confidence intervals were obtained from 10,000-time bootstrap resampling. All statistical analyses were performed using the R software program, version 3.6.0 (R Development Core Team, Vienna, Austria).

Results

The clinical characteristics of the study population are summarized in Table 1. The mean age was 66±11 years, and the prevalence of diabetes mellitus, dyslipidemia, hypertension, and hyperuricemia was 76.5%, 75.2%, 66.7%, and 12.1%, respectively. Seventy-seven patients (7.7%) were diagnosed with a decreased masticatory function. Patients with a decreased masticatory function had an older age and a higher proportion of obesity, diabetes mellitus, decline in gait speed, decline in handgrip strength, denture use, and feeling difficulty eating hard food than those without a decreased masticatory function (Table 1). The mean color scale and delta E of the color-changeable chewing gum test were 6.7±1.8 points and 42.9±6.7 units, respectively. The scatter plots between the gummy jelly test and color-changeable chewing gum test are shown in Fig. 1.

Fig. 2A illustrates the ROC curves of the color-changeable chewing gum test. The area under the ROC curve of the color scale and delta E was 0.822 (95% confidence interval, 0.768 to 0.872) and 0.838 (0.781 to 0.890), respectively (p=0.41). The sensitivity and specificity corresponding to an arbitrary cut-off point are shown in Fig. 2B and C. As demonstrated in Table 2, the optimal cut-off point of the color scale was 5.5 (5.0 to 6.5) points, whereas that of delta E was 37.7 (35.5 to 38.8) units. The optimal cut-off points were not significantly different between the subgroups divided by clinical characteristics (Fig. 3).

Discussion

The current study demonstrated the screening performance of a color-changeable chewing gum test for a decreased masticatory function in patients with metabolic diseases. The area under the ROC curve of the color scale and delta E was 0.822 (0.768 to 0.872) and 0.838 (0.781 to

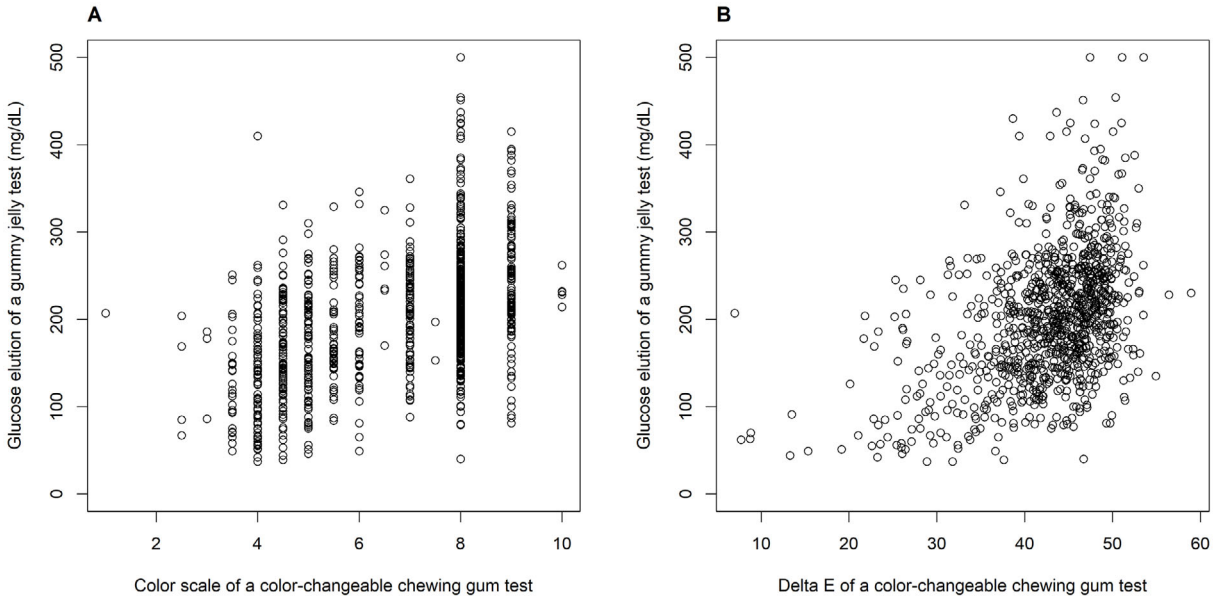

Figure 1. **Scatter plots comparing the color scale of a color-changeable chewing gum test and glucose elution of a gummy jelly test (A) and the delta E of a color-changeable chewing gum test and glucose elution of a gummy jelly test (B).**

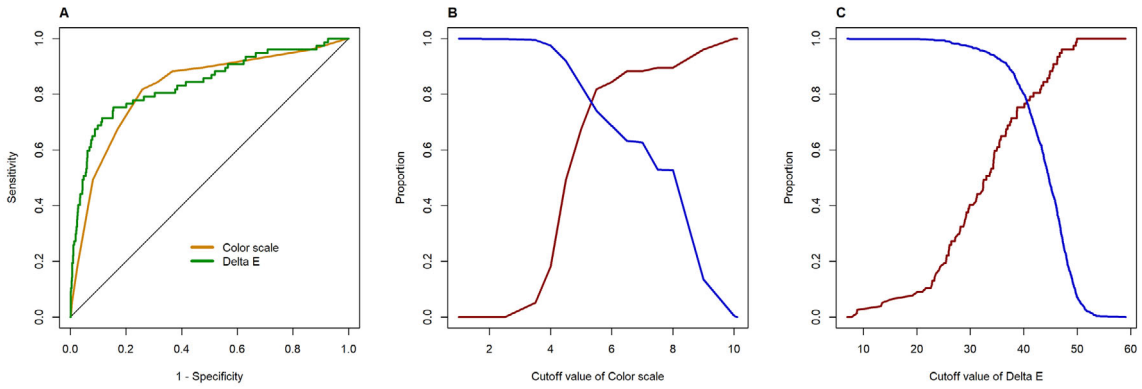

Figure 2. **Screening performance of a color-changeable chewing gum test for a decreased masticatory function assessed by a gummy jelly test. Panel A: ROC curves of the color scale (orange line) and delta E (green line) of the color-changeable chewing gum test for a decreased masticatory function. The area under the ROC curve of the color scale and delta E was 0.822 (95% confidence interval, 0.768 to 0.872) and 0.838 (0.781 to 0.890), respectively (p=0.41). Panel B and C: Plots of the sensitivity (red line) and specificity (blue line) corresponding to arbitrary cut-off values of the color scale (panel B) and delta E (panel C). The sensitivity indicates the percentage of cases (i.e. patients with a decreased masticatory function) whose value of interest was lower than an arbitrary cut-off point in all cases, whereas specificity indicates the percentage of controls (i.e. patients without a decreased masticatory function) whose value of interest was equal to or higher than an arbitrary cut-off point in all controls.**

0.890), respectively. The optimal cut-off point was 5.5 (5.0 to 6.5) points for the color scale and 37.7 (35.5 to 38.8) units for delta E. The optimal cut-off points were not significantly different regardless of clinical characteristics.

Patients with a decreased masticatory function assessed by a gummy jelly test had an older age and a higher proportion of obesity and diabetes mellitus, decline in gait speed, and decline in handgrip strength, and denture use than those without a decreased masticatory function. People with old age, obesity, and diabetes mellitus are at a high risk of periodontitis, a major cause of tooth loosening and loss (5, 26, 27). Cross-sectional studies have demonstrated a correlation between these clinical characteristics and a decreased masticatory function (28-30). Recent studies also suggest a close relationship between a decreased masticatory function and frailty or sarcopenia (31, 32). A decline in gait

Table 2. ROC Curves of the Color-changeable Chewing Gum Test for Decreased Masticatory Function.

	Color scale	Delta E
Area under the ROC curve	0.822 [0.768 to 0.872]	0.838 [0.781 to 0.890]
Optimal cutoff point determined by the Youden index	5.5 [5.0 to 6.5]	37.7 [35.5 to 38.8]
Sensitivity corresponding to the optimal cutoff point (%)	81.8 [69.9 to 91.8]	71.4 [62.1 to 84.0]
Specificity corresponding to the optimal cutoff point (%)	74.1 [63.3 to 84.0]	88.6 [82.3 to 93.0]

Data are estimates [95% confidence intervals].

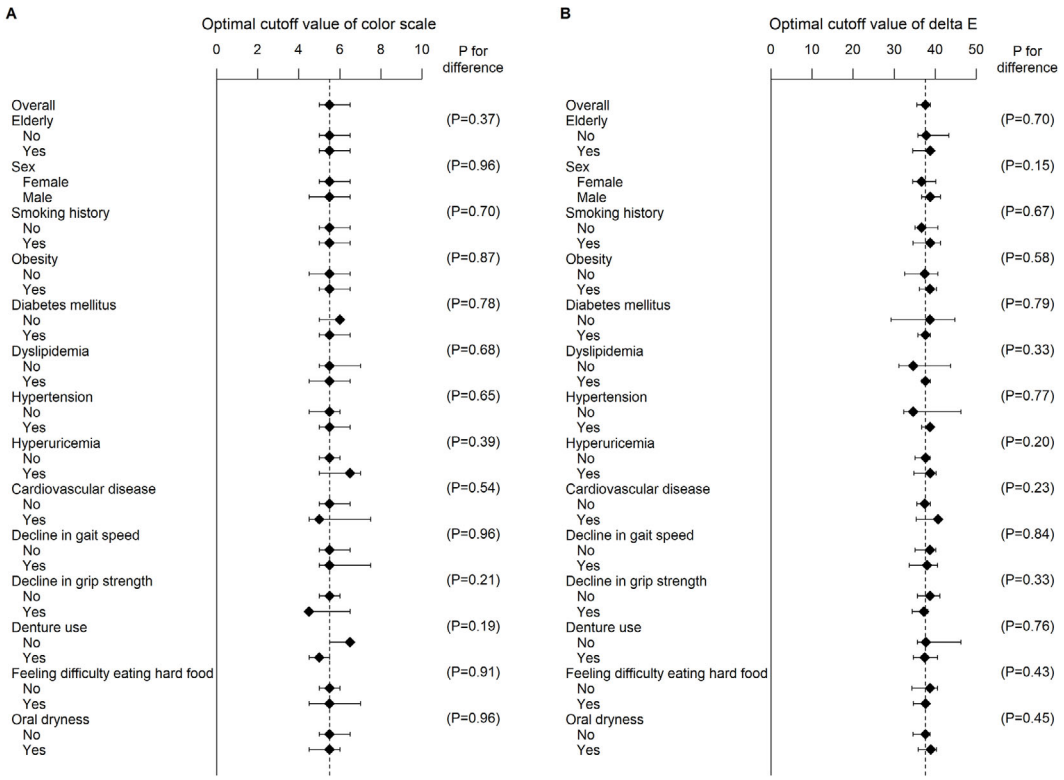

Figure 3. Optimal cut-off points of color scale (panel A) and delta E (panel B) of the color-changeable chewing gum test in subgroups. Error bars represent 95% confidence intervals. p values are for the between-group difference.

speed and handgrip strength are well-known markers of frailty and sarcopenia (22, 33). Denture use is also an epidemiological marker of a decreased masticatory function. Although replacing missing teeth with dentures can improve mastication, such compensation cannot reach the efficiency of a complete set of natural teeth (34). The current findings are consistent with those reports. The association between a decreased masticatory function determined by a gummy jelly test and feeling difficulty eating hard food (i.e. a subjective assessment) would also indirectly suggest the validation of the assessment of a decreased masticatory function by a gummy jelly test.

Patients with metabolic diseases are expected to be at high risk of a decreased masticatory function. The treatment for a decreased masticatory function might lead to the improvement of metabolic control as well as a reduction in the risk of physical frailty. It is clinically useful to detect patients suspected of having a decreased masticatory function and refer them to a dentist for a diagnosis and intervention. In the assessment of oral hypofunction, a decreased masticatory function is currently diagnosed by a gummy jelly test (3). However, subjects are obliged not to swallow any pieces of the chewed jelly while chewing it, which is not always physiological and can be challenging to some subjects. Furthermore, collecting all pieces of the jelly spit out for the evaluation is challenging in some clinical settings. In contrast, a color-changeable chewing gum test seems a simple, attractive tool for the evaluation of the masticatory performance in clinical practice. We demonstrated that the area under the ROC curve was 0.822 (0.768 to 0.872) for the color scale and 0.838 (0.781 to 0.890) for delta E, suggesting that the screening performance of the gum test was practically satisfactory for a screening tool. In the clinical setting, the gum test can be used to screen patients with metabolic diseases.

The colorimetric measurement is a reliable, objective way

to quantify the change in color. However, it requires specialized measuring equipment, so a simple assessment using a color scale is advantageous compared with this approach. The current study demonstrated that the area under the ROC curve of the color scale was not significantly different from that of delta E, indicating that the screening performance of the color scale assessment was not inferior to that of the colorimetric measurement. The color scale seems to be a convenient and useful tool for screening patients with metabolic diseases for the risk of a decreased masticatory function.

Patients with metabolic diseases are a heterogenous population. They include different age groups, and the comorbidities vary from patient to patient. Some are at a high risk of frailty, whereas others are not. However, the present study confirmed that nonetheless the optimal cut-off point in a color-changeable chewing gum test for detecting a decreased masticatory function was not different between subgroups stratified by clinical characteristics (Fig. 3). Patients with metabolic diseases can be screened using one cut-off value, regardless of their clinical characteristics.

Several limitations associated with the present study warrant mention. First, a chewing gum is a different food form from a gummy jelly. Mastication is comprised of several processes that include shearing, crushing, grinding, and mixing, and the involvement of these respective processes during mastication varies from food to food. Therefore, the use of a different food form would evaluate a different aspect of mastication. Second, the chewing rate was controlled at once per second during a color-changeable chewing gum test, in accordance with the instruction manual (23). Since the color reaction of the test gum can proceed with time, it is important to control time for chewing, in addition to the number of chewing strokes, during the test. However, mastication with a controlled chewing rate would differ from that with usual and habitual mastication. The study subjects underwent a gummy jelly test using their own preferred chewing rate. Any difference in the chewing rate would affect the study findings. Third, during a gummy jelly test, subjects were obliged not to swallow any pieces of the chewed jelly while chewing it, which would be challenging to some subjects. Furthermore, collecting all pieces of the jelly spit out would not always be easy. The current study adopted a gummy jelly test as a reference, simply because the test is currently the only modality available for diagnosing a decreased masticatory performance in the assessment of oral hypofunction (3). However, these challenges would affect the diagnostic accuracy of a decreased masticatory function. Fourth, a color-changeable chewing gum test utilizes a color reaction in the presence of saliva, and a decrease in saliva secretion could affect the test result. Although we confirmed that oral dryness did not affect the cut-off point for the chewing gum test (Fig. 3), this was evaluated in a non-chewing state. How consistent the judgement of oral dryness would be with a decrease in saliva secretion during mastication is unclear. Fifth, this study analyzed patients with metabolic diseases, and whether or not a color-changeable chewing gum test would have a similar screening performance in other populations was not assessed. Sixth, we did not evaluate the dental articulation or periodontal conditions, nor did we perform a kinetic analysis during mastication. Finally, this was a single-center study conducted in Japan, and future external validation will be needed.

In conclusion, the current study demonstrated the screening performance of a color-changeable chewing gum test for a decreased masticatory function in patients with metabolic diseases. The area under the ROC curve of the color scale and delta E was 0.822 (0.768 to 0.872) and 0.838 (0.781 to 0.890), respectively. The optimal cut-off point was 5.5 (5.0 to 6.5) points for the color scale and 37.7 (35.5 to 38.8) units for delta E. The optimal cut-off points were not significantly different regardless of clinical characteristics.

Author's disclosure of potential Conflicts of Interest (COI).
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