Original Article

A Comparative Study of Chewing Efficiency using 3 Evaluation Methods

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Abstract

The purpose of this study was to compare 3 chewing efficiency evaluation methods and determine if there was any correlation between their results when testing under the same group of subjects. The test items used in the 3 methods were red /green wax cubes (system 1), chewing gum (system 2) and red/white wax cubes (system 3). Seventeen subjects wearing lower unilateral distal extension removable dental prostheses (RDP) (4 males and 13 females, mean age 56.59±10.79 years) participated in this study. The subjects were asked to chew the test items in system 1 to system 3 for 10, 25 and 10 strokes respectively in the same visit in the order of systems 1, 2, and 3. Subjects were asked to chew the test items on each side (left and right) with and without their lower prostheses. The chewing efficiency obtained from system 1, 2 and 3 were mixing ability index (MAI), mean a* (the value of green-magenta axis) and percentage of chewing ability, respectively. Statistical analysis revealed a significant difference ($p < .05$) in chewing efficiency between chewing with and without prosthesis with all three chewing efficiency test systems. Pearson's correlation coefficients between systems showed the three systems were significantly related to each other ($p < .05$). Also, this study revealed that any of the three chewing efficiency systems could be alternatively used depending on the circumstances or the economic base of investigating group. Our results suggested that the two-colored (red/white) wax cube system was the one option for evaluating the chewing ability.

Introduction

In dental treatment, restoration of natural teeth or replacement of missing teeth is performed to rehabilitate and restore masticatory function, leading to better food digestion, absorption, and quality of life.[1-3] The evaluation of masticatory function can be divided into two methods. One is subjective evaluation by using questionnaires or patient interviews; however, the results are unreliable as they are based on the patient's interpretation, thus incomparable between subjects.[4-6] Another method is objective evaluation which, being quantitative, allows for comparison with other studies.[7,8] Previously, the majority of the studies on chewing ability were based on the degree of breakdown of a food, such as peanuts, carrots or almonds, by analyzing the volume of the comminuted food[8-13] by sieving. Nevertheless, this method can be inaccurate as food may be dissolved or swallowed while chewing.[12,13] Subsequently, researchers developed the mixing ability test which is based on the ability of chewing to mix a food bolus. Chewing

gum[14-16] and two-colored wax cubes[17,18] have been used as test food for the quantification of masticatory performance under this paradigm. Recently, several systems[14,16,17] have been introduced to the market such as low adhesive colour-developing chewing gum or two-colored paraffin wax cube. For example, Prapatrungsri *et al*[19] developed a two-colored wax cube which was assayed for use by subjects having normal dentition. However, to our knowledge, there are no studies which compare these systems and find their correlations when tested by the same group of subjects. Also, the outcome of this study may be used to determine the most convenient system to evaluate the chewing ability of dental patients at chair side. The objective of this study was to compare 3 chewing efficiency evaluation methods and determine if there was any correlation between the three methods when testing under the same group of subjects.

Materials and methods

Subjects of this study included Thai patients recruited from the student's patient bank of the Department of Prosthodontics, Faculty of Dentistry, Chulalongkorn University. This study was approved by the Institutional Review Board of Chulalongkorn University. All subjects signed informed consent prior to beginning the study. Inclusion criteria for the study were (1) the subjects wore a lower unilateral distal extension removable dental prosthesis (RDP) replacing first premolar to second molar teeth on the distal extension side while the contralateral side having normal dentition or fixed dental prosthesis, (2) the patient had no complaint regarding the prosthesis, (3) the prosthesis did not require adjustment, (4) the patient had been wearing the denture for 3 months to 1.5 years with no acute or chronic symptoms of temporomandibular disorders, (5) The opposing dentition must be normal dentition, fixed dental prosthesis, tooth borne RDP or a unilateral distal extension RDP that their artificial denture teeth on the distal extension side not occlude with artificial denture teeth of the lower distal extension RDP. According to these criteria, a total of 17 subjects (4 males and 13 females, mean age 56.59±10.79 years) were selected. Each subject's chewing efficiency was evaluated using 3 systems in the same visit in the order of system 1, 2, and then 3. Each subject was told to chew one piece of the test sample on the right side with their lower prosthesis and duplicate the process again with another test sample without their prosthesis. After finished chewing on the right side, then the subject was told to repeat all of above chewing process on the left side. Also, each subject generated the data with and without their prosthesis in both distal extension side (partial edentulous side) and dentition side which used in further statistical analysis.

System 1

A mixing ability test was performed to estimate food mixing ability.[17] Two-colored (red/green) paraffin wax cubes (12x12x12 mm.) developed by Sato *et al*[17] (Fig. 1a) were kept in an incubator (Contherm160M, Contherm Scientific Ltd., New Zealand) at 37°C for 24 hours and soaked in a water bath (Isotemp202, Fisher Scientific Co., Ltd, Japan) at 37 C for further 10 minutes prior to the test. Each subject sat in an upright position on the dental unit and was instructed to chew a wax cube (red/green) for exactly 10 strokes on the right side then removed and 10 strokes on the left side with another wax cube with and without their prosthesis according to the recommended procedure of these system. The chewed wax was removed from the oral cavity of the subject (Fig. 1b), rinsed under tap water for 20 seconds, and then soaked in 70 percent concentration of ethyl-alcohol for 5 minutes.

Monochrome and color digital images of both sides of the chewed wax were taken using a color charge-coupled device (CCD) camera (XC-003, Sony Co., Tokyo, Japan) under standardized light-emitting diode lighting conditions.[17] Subsequently, five parameters regarding the degree of color mixing and the shape of the chewed wax cubes were measured from the images using an image analyzer (Luzex-FS, Nireco Co., Tokyo, Japan) that is the ratio of color mixed area, the ratio of area above 50 μm in thickness to total projection area, the ratio of maximum length to maximum breadth, the shape factor that shows how flat the sample is and the total projection area.[17] The Mixing Ability Index (MAI) was obtained for both side of the chewed cube by input of the parameters into a formula determined by discriminant analysis as follows.[17]

$$MAI = 1.360 \times 10^{-1} \times MIX + 2.950 \times 10^{-1} \times (TR) + 3.584 \times 10^{-3} \times (LB) - 2.032 \times 10^{-3} \times FF + 7.950 \times 10^{-4} \times (AH) - 12.62$$

(MIX, the ratio of color mixed area; TR, the ratio of area above 50 m in thickness to total projection area; LB, the ratio of maximum length to maximum breadth; FF, the shape factor shows how flat the sample is; and AH, the total projection area)

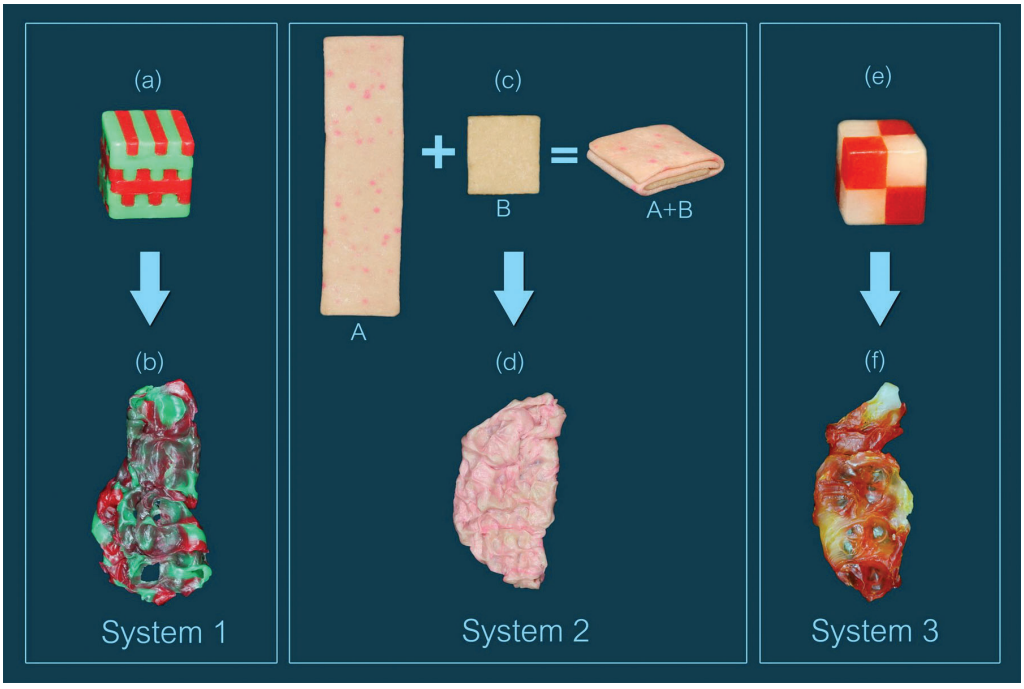

Fig.1 System 1 (a) The Green-red wax cube before chewing, (b) The chewed wax after 10 chewing strokes. System 2 (c) The chewing gum before chewing (pieces A and B), (d) The chewed gum after 25 chewing strokes. System 3 (e) The Red-white wax cube before chewing, (f) The chewed wax after 10 chewing strokes

System 2

Low-adhesive color developing chewing gum (MEIJI, Japan) was used in a mixing ability test by Matsui *et al.*[14] The chewing gum consisted of two pieces (A, 20x50x1.5 mm. and B, 20x20x1.5 mm.) folded together (Fig. 1c). The A piece contained phloxine, a safe food additive, which develops a red color in an alkaline environment, and the B piece contained sodium bicarbonate ($NaHCO_3$), which is alkaline and can change the color of the phloxine.[14] Each subject sat in an upright position on the dental unit and was instructed to chew the chewing gum for 25 strokes on the right side then removed and 25 strokes on the left side with another chewing gum with and without their prosthesis according to the recommended procedure of these system. The chewed gum (Fig. 1d) was removed from the oral cavity of the subject, wiped gently with a tissue paper, placed in a polyethylene bag, flattened between two plates of glass slab to be 1 mm. thickness and randomly measured for color by a color reader (CR-10, KONICA MINOLTA, Tokyo, Japan) at 10 points on both sides of each specimen. The color was evaluated using the L*a*b* color space, developed by CIE (Commission Internationale de l'Eclairage, 1976) for measuring an object's color. The green-magenta axis (a*) was evaluated in this study because this chewing gum color fell into the red axis. The mean value of 10 a* was calculated and used for analysis.

System 3

A two-colored (red/white) wax cube has been developed at Chulalongkorn University to estimate food mixing ability.[19] The wax cubes (Fig. 1e) were kept in an incubator (Contherm160M, Contherm Scientific Ltd., New Zealand) at 37°C for 24 hours and soaked in a water bath (Isotemp202, Fisher Scientific Co., Ltd, Japan) at 37°C for further 10 minutes prior to the test. Each subject sat in an upright position on the dental unit and was instructed to chew a wax cube (red/white) for exactly 10 strokes on the right side then removed and 10 strokes on the left side with another wax cube with and without their prosthesis according to the recommended procedure of these system. The chewed wax was removed from the oral cavity of the subject (Fig. 1f), rinsed under tap water for 20 seconds, and soaked in 70 percent concentration of ethyl-alcohol for 5 minutes.

Images of both sides of the chewed wax were captured by the digital camera (Canon EOS 450D, Canon Inc., Tokyo,

Japan) with a macro lens (Canon macro 100 mm.) under standardized lighting conditions (a photo stand kit; Copy stand CS920 and Copy light CL-150 with 2 light bulbs; Philips® Cool Daylight 125 Watts, Color temperature 6,500 K and a lux meter; DigiconLX-70, Protonics Inter-trade Co, Ltd., Thailand). All images were transferred and analyzed by Image J program (Version 1.42Q, NIH, MD, USA). The standard color value, representing well mixed red and white color wax, was obtained by mixing an equal amount (by weight) of red wax and white wax until a uniform color of the mixture was achieved. The Image J program was used to define color into specific color value; ranging between 0 (white color) to 255 (black color).[19] The program also automatically calculated number of color values, as well as number of pixels within the define area. After the analyzing process, Image J program showed the standard color value was in the range of 20-40.[19] The percentage of chewing ability was computed by the following formula: Total number of pixels of standard color value x 100 / Total number of pixels of the chewed wax.[19]

The correlation among MAI, mean a and percentage of chewing ability*

Paired-t test was used for comparing the data of MAI, a* and percentage of chewing ability of each subject with and without the prosthesis installed in distal extension side (partial edentulous side). Pearson's correlation coefficient was used to evaluate the relationships between systems by the differences obtained from partial edentulous side with and without prosthesis of each system. Statistical analysis was performed with the Statistics Package for the Social Sciences (SPSS) version 17.0 (SPSS (Thailand) Co., Ltd., Bangkok, Thailand). In all statistical analysis, a p-value less than .05 was considered significant.

Results

The data from each system was analyzed for the partial edentulous side and dentition side. The differences obtained from partial edentulous side with and without prosthesis among the 3 systems were used for statistical analysis. Because of a limitation of time, budget and number of the subjects who meet all of the criteria were limited, total number of the subjects in this current study was only 17 subjects. However, results from SPSS program showed the data in each system was normally distributed. Means and standard deviations (s.d.) of partial edentulous side and dentition side from each system are shown in Table 1. In all systems tested, the natural dentition side with the prosthesis in place had the best and the prosthesis side without the prosthesis in place had the worst chewing ability. Statistical analysis revealed a significant difference ($p < .05$) between with and without prosthesis installed in partial edentulous side for all 3 chewing efficiency test systems (Table 1).

Pearson's correlation coefficients between systems are shown in Table 2. The difference in MAI, system 1, was significantly related to both the differences of mean a*, system 2, ($r = 0.885$, $p < .001$) and the difference in percentage of chewing ability, system 3, ($r = 0.850$, $p < .001$). The difference of mean a* was significantly related to the difference in percentage of chewing ability ($r = 0.708$, $p = .001$).

Discussion

The results of this study indicated the all chewing efficiency methods tested were capable to discriminate masticatory performance of the subject with or without distal extension removable dental prosthesis. Also, the results indicated the three systems in this study could detect the differences and the improvement of chewing efficiency on the partial edentulous side both with and without prosthesis. The effects on chewing ability based on the design of the lower RDPs were not included in this study.

However, the results from each system could not be compared to each other directly because they were assayed using different indexes. So, we only considered differences of the individual tests showing improvement of chewing efficiency to compare and to find any correlation between them. Larger t-values were observed for system 2 than system 3 and system 1, respectively. This indicates that system 2 better detects differences in chewing efficiency with and without prosthesis than system 3 and system 1 which might result from differences in chewing stroke, softness or even size of the test materials. Van der Bilt A. *et al,*[20] reported the mixing ability test with the two-colored chewing gum is a good method to determine masticatory function in subjects with compromised masticatory performance. In the present study system 2 using a low-adhesive color-developing chewing gum as a media, showed the same result. Because the chewing gum has the advantage of forming a bolus and is easy to manipulate, this makes this test food suitable for subjects with compromised oral function. However, chewing gum may less suitable for subjects with a good masticatory

Table 1 *Chewing efficiency measured by 3 evaluation systems. Mean and standard deviation of the groups and statistical significance of differences in the results for the groups of with and without lower removable dental prosthesis on the partial edentulous side are given*

	Dentition side		Partial edentulous side			
	Without LRDP	With LRDP	Without LRDP	With LRDP		
	Mean±s.d.	Mean±s.d.	Mean±s.d.	Mean±s.d.	*t*-value	*p*-value
System 1(MAI)	-0.63±1.48	0.06±1.35	-1.36±1.21	-0.21±0.98	- 4.831	< .001
System 2(a*)	34.49±2.81	37.21±2.04	31.56±4.52	41.01±5.58	- 7.444	< .001
System 3 (percentage of chewing ability)	31.47±5.46	33.48±6.16	23.93±5.82	27.95±6.40	- 5.240	< .001

Remarks: LRDP; Lower removable dental prosthesis, s.d.; Standard deviation, MAI; Mixing ability index

Table 2 *Pearson's correlation coefficient between chewing efficiency tests*

Relationship	r	*p*-value
System 1 versus System 2	0.885	< 0.001
System 1 versus System 3	0.850	< 0.001
System 2 versus System 3	0.708	0.001

performance as the mixing of the two colors is too easy.[20] Sato H. *et al,*[17] reported a significant difference in MAI measured using system 1 with and without a removable dental prostheses. This result indicates the method is suitable for intra-individual research in comparison with other studies. Two-colored wax cubes have many advantages in chewing efficiency testing because it is easy to perform the test and simple to analyze the subsequent samples.[17] However, results from a previous study of system 3[19] showed an ability to identify chewing ability among subject but had no data on compromised subjects such as partial or total edentulous subjects. Furthermore, the results indicated chewing efficiency on both partial edentulous side and dentition side were improved when the lower prosthesis was in place. A limitation of the current study is that it did not focus on the design of the RDP, variation of edentulous patterns, age or gender of the subjects and order of the test system. So, we can only conclude that wearing a removable prosthesis on the distal extension (partial edentulous) side could improve the chewing efficiency on both the dentition and partially edentulous side. Significant correlations between the three chewing efficiency test systems were observed for the difference in the results chewing efficiency on the partial edentulous side with and without prosthesis. Our results indicated the three systems were significantly related to each other. Also, this study revealed that the three chewing efficiency systems could be used interchangeably depending on the circumstances or the economic base of investigating group. The two-colored wax cube developed by Prapatrungsri *et al*[19] was shown to have low cost and time requirements. The ease of use and analysis combined with low cost make the two-colored (red/white) wax cube system an excellent option for evaluating the chewing ability of Thai patients.

In conclusion, the two-colored (red/white) wax cube is a new artificial test food developed in Thailand. It has no taste as well as no smell. Unlike with other formulations, no participant of our study refused to chew this cube. Some problems still exist such as the wax cube sticking to the artificial teeth or hardness of the wax cube. In this study, only the distal extension was evaluated among many factors of chewing ability. Other factors such as number of teeth replaced on the partial edentulous (distal extension) side, number of functional tooth units, designs of the

removable dental prostheses, type of the opposing dentition, order of the test system or hardness of the test food remain to be compared in further studies.

Conclusion

The results of this study suggest that three chewing efficiency systems were significantly related to each other and lead us to use system that suit with the circumstance instead of the other systems. However, we may conclude that the two-colored (red/white) wax cube system is the one option for evaluate the chewing ability of the Thai patients.

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บทวิทยาการ
Original Article

การเปรียบเทียบประสิทธิภาพการบดเคี้ยวภายใต้วิธีการประเมิน 3 ระบบ

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บทคัดย่อ

การศึกษานี้มีวัตถุประสงค์เพื่อเปรียบเทียบประสิทธิภาพการบดเคี้ยวด้วยวิธีการประเมิน 3 ระบบ และศึกษาความสัมพันธ์ของแต่ละระบบ วัสดุที่ใช้ในการประเมิน 3 ระบบ ได้แก่ ชิ้นขี้ผึ้งสีแดงเขียว (ระบบที่ 1) หมากฝรั่ง (ระบบที่ 2) และชิ้นขี้ผึ้งสีแดงขาว (ระบบที่ 3) อาสาสมัครที่ใส่ฟันเทียมบางส่วนถอดได้ขยายฐานด้านไกลกลางเดียวในขากรรไกรล่างจำนวน 17 คน (ชาย 4 คน หญิง 13 คน อายุเฉลี่ย 56.59±10.79 ปี) เคี้ยวอาหารทดสอบในระบบที่ 1 2 และ 3 จำนวน 10 25 และ 10 ครั้งตามมาตรฐานของแต่ละระบบตามลำดับ โดยเคี้ยวอาหารทดสอบทั้ง 2 ข้าง (ซ้ายและขวา) เมื่อใส่และไม่ใส่ฟันเทียม ค่าประสิทธิภาพในการบดเคี้ยวที่ได้จากระบบที่ 1 คือ ดัชนีชี้วัดความสามารถในการผสม (Mixing Ability Index) ระบบที่ 2 คือ ค่าเฉลี่ยของสีในแกนสีเขียว-ม่วง และระบบที่ 3 คือ ค่าเฉลี่ยร้อยละความสามารถการบดเคี้ยว ผลการศึกษาพบว่า การประเมินประสิทธิภาพการบดเคี้ยวระหว่างการใส่และไม่ใส่ฟันเทียมบางส่วนถอดได้ขยายฐานด้านเดียวในขากรรไกรล่างทั้ง 3 ระบบมีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติ ($p < .05$) จากค่าสัมประสิทธิ์สหสัมพันธ์เพียร์สันพบว่า ทั้ง 3 ระบบมีความสัมพันธ์กันอย่างมีนัยสำคัญทางสถิติ ($p < .05$) ทำให้สามารถใช้ระบบที่เหมาะสมกว่าแทนระบบอื่นได้ขึ้นอยู่กับสภาวะหรือเศรษฐานะของผู้ป่วย การศึกษานี้แนะนำว่าชิ้นขี้ผึ้งสีแดงขาวเป็นอีกทางเลือกหนึ่งที่สามารถนำมาใช้ในการประเมินประสิทธิภาพในการบดเคี้ยว