A Comparative Study of Chewing Efficiency using 3 Evaluation Methods

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 food9-13 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\textsuperscript{14-16} and two-colored wax cubes\textsuperscript{17,18} have been used as test food for the quantification of masticatory performance under this paradigm. Recently, several systems\textsuperscript{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 \textit{et al}\textsuperscript{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.\textsuperscript{17} Two-colored (red/green) paraffin wax cubes (12x12x12 mm.) developed by Sato \textit{et al}\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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)
System 2

Low-adhesive color developing chewing gum (MEIJI, Japan) was used in a mixing ability test by Matsui et al. 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 (NaHCO₃), which is alkaline and can change the color of the phloxine. 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. 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). 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. 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.

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. 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.

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. reported the mixing ability test with the two-colored 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
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. However, results from a previous study of system 3 showed an ability to identify chewing ability among subjects 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 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

### 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.

<table>
<thead>
<tr>
<th></th>
<th>Dentition side</th>
<th>Partial edentulous side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without LRDP</td>
<td>With LRDP</td>
</tr>
<tr>
<td></td>
<td>Mean±s.d.</td>
<td>Mean±s.d.</td>
</tr>
<tr>
<td>System 1(MAI)</td>
<td>-0.63±1.48</td>
<td>0.06±1.35</td>
</tr>
<tr>
<td>System 2(a*)</td>
<td>34.49±2.81</td>
<td>37.21±2.04</td>
</tr>
<tr>
<td>System 3</td>
<td>31.47±5.46</td>
<td>33.48±6.16</td>
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</tbody>
</table>

(percentage of chewing ability)

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

### Table 2
Pearson’s correlation coefficient between chewing efficiency tests

<table>
<thead>
<tr>
<th>Relationship</th>
<th>r</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>System 1 versus System 2</td>
<td>0.885</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>System 1 versus System 3</td>
<td>0.850</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>System 2 versus System 3</td>
<td>0.708</td>
<td>0.001</td>
</tr>
</tbody>
</table>
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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**References**

การเปรียบเทียบประสิทธิภาพการระบายยาได้รับการประเมิน 3 ระบบ

ศิริยา เฉลิมบุญพันธุ์

ประกาศเรียก ใจชัยพากูล

การศึกษาวิเคราะห์ประสิทธิภาพการระบายยาได้รับการประเมิน 3 ระบบ และศึกษาความสามารถพันธุ์ของแต่ละระบบ วัสดุที่ใช้ในการประเมิน 3 ระบบ ได้แก่ ขั้นชื่อสิ่งเดิมเขียว (ระบบที่ 1) หมายถึง ระบบที่ 2 และขั้นชื่อสิ่งเดิมขาว (ระบบที่ 3) สารละลายที่ผลิตภัณฑ์ส่งผลต่อยอดได้ข้อกฏฐานด้านกลไกการรักษาจำแนกจำนวน 17 คน เขียน 4 คน ปรับ 13 คน อยู่เรียบร้อย 56.59±10.79 ปี) เดินทางระหว่างลงในระบบที่ 1 และ 3 จำนวน 10 25 และ 10 ครั้งตามมาตรฐานของแต่ละระบบตามลำดับ โดยเดียวอาหารที่จะขึ้น 2 ขั้น (ช่วยและขวาง) เนื่องจากอยู่ไม่ได้พัฒนาระบบประสิทธิภาพในการระบายยาได้จากระบบที่ 1 คือ การศึกษาความสามารถในการผสม (Mixing Ability Index) ระบบที่ 2 คือ คำว่าขั้นของที่ 3 รวมไปถึงขั้นของที่ และระบบที่ 3 คือ คำว่าขั้นของการระบายยาได้รับการเดิม ผลการศึกษา พบว่า การประเมินประสิทธิภาพการระบายยาได้รับการเดิมและไม่ได้พัฒนาความสูงต่ำได้ข้อกฏฐานด้านกลไกการรักษาจำแนก 3 ระบบมีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติ (p < .05) จากค่าดิฟเฟอร์ชั่นสิ่งพันธุ์เพื่อสังเกตุาว่า ทั้ง 3 ระบบมีความสัมพันธ์กันอย่างมีนัยสำคัญทางสถิติ (p < .05) ทำให้สามารถใช้ระบบที่เหมาะสมกับแผนระบบเดิมได้เช่น การศึกษาต่างๆมีความสัมพันธ์กันอยู่กับสาระของชีวิตหรือชีวิตของผู้ป่วย การศึกษาหรือแปลงขั้นชื่อสิ่งเดิมขาวเป็นขั้นทางเลือกที่สามารถนำมาใช้ในการประเมินประสิทธิภาพในการระบายยาได้