Original Article

The Development of Wax Cubes Hardness for Chewing Ability Evaluation

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Abstract

The purposes of this study were to develop the optimal wax cube hardness for evaluating the chewing ability of totally edentulous patients wearing complete dentures and to find the suitable hardness for patients with chewing ability close to those of normal dentition. Three formulations of wax cubes, hard, original, and soft, were developed by mixing different ratios of bees wax and microcrystalline wax. The hardness's of the three types of wax cubes and sixteen common foods were determined using a Universal Testing Machine (SHIMADZU®). Twenty patients with normal dentitions (mean age 27.85±1.42 years), twenty patients with complete dentures (mean age 70.55±9.14 years) and twenty patients with implant-retained lower complete dentures (mean age 67.70±6.68 years) were selected. Each subject chewed three wax cube pieces sequentially, of each hardness type, for 10 chewing strokes using habitual chewing patterns. The chewed wax images were captured and analyzed by the Image J program (NIH), which calculated the percentage of well-mixed color areas. Statistical analysis revealed a significant difference ($p < .05$) in percentage of chewing ability between the normal dentition group, the complete denture group, and the implant-retained lower complete denture group when chewing original and soft wax cubes. The complete denture group had an approximately 35 percent reduction in chewing percentage when chewing original and soft wax cubes compared to the normal dentition group. The implant-retained lower complete denture group showed a higher percentage of chewing ability than the complete denture group. We conclude that the best wax cube hardness for use in chewing ability evaluation of total edentulous patients with complete dentures are the original and soft wax cubes, which are in the same range as common food we tested. The hard wax cube hardness was difficult to chew, and beyond the food hardness range. Our results suggest that the two-colored wax cube is an option for screening chewing ability and should be accompanied by some nutritional assessment tools to evaluate nutritional status in the elderly patients.

Introduction

The quality of life of the edentulous elderly population is influenced by many factors, such as the loss of teeth, decreased food ingestion, and poor diet.[1] Previous studies have demonstrated a relationship between edentulousness and diet.[2-4] Totally edentulous adults who wear complete dentures encounter difficulty in chewing food, requiring an adjustment their dietary habits to a soft, easy-to-chew, low fiber diet, often containing high amounts of carbohydrates and fats. This can lead to malnutrition.[5-7] Studies

have stated that consequently edentulous patients are at a higher risk of developing serious cardiovascular disease and bowel cancer.[8,9]

In dental prosthetic treatment, the restoration of natural teeth or the replacement of missing teeth is performed to recover masticatory function. Various chewing tests have been developed to evaluate masticatory function. The evaluation of masticatory function can be divided into two methods. The first is a subjective evaluation using questionnaires or patient interviews.[2,10,11] The other is an objective quantitative evaluation, allowing for comparison with other studies[12,13] such as the sieving method,[13-18] the chewing gum method,[19-21] and the wax cube analysis method.[22-24] A two-colored (red/white) wax cube has been developed by Prapatrungsri et al. to estimate an individual's food mixing ability.[24] This method was used to evaluate the chewing ability after dental treatment both in patients with normal dentition[24] and removable dental prostheses.[25] Chewing ability in those studies was determined by evaluating the color of the well-mixed wax area, the so called "standard color value". This area is generated by the blending of the white and red wax cubes together under the controlled chewing strokes of the subjects.[24] The chewed wax with values close to that of the standard color value represents better chewing ability.[24]

Because wax cubes with different levels of hardness can simulate some common foods, these can be used for determining the chewing ability of elderly patients. The result of the analysis can suggest suitable foods for each patient. The aims of this study were to determine the best wax cube hardness for use in chewing ability evaluation and find the suitable hardness of foods that allow total edentulous patients to have chewing ability close to normal dentition.

Materials and methods

Development wax cube hardness

The two-colored (red/white) wax cube used in previous studies[24,25] is composed of a mixture of Bees wax (70% by weight) and Microcrystalline wax (30% by weight). Two new formulations of wax cubes, a softer wax cube (50% Bees wax and 50% Microcrystalline wax), and a harder wax cube (85% Bees wax and 15% Microcrystalline wax) of different colors were developed (Fig.1). The colorant used in this study is a food grade oil-based dye (Blue; Lake Brilliant Blue, Red; Lake Ponceau 4R, Yellow; Lake Tartrazine, Vinayak Corporation, Mumbai, India).

Twenty-five elderly Thai patients (mean age 72±7.87 years) were interviewed about the types of food they frequently consumed. The sixteen most common foods (boiled Chinese kale, fresh apple, boiled baby corn, fresh guava, boiled pumpkin, boiled fish ball, boiled Chinese cabbage, cooked jasmine rice, boiled pork, hard-boiled egg, fresh cow-pea, boiled cow-pea, plain omelet, fried fish, fresh cucumber, and fried pork), named were selected to represent the most frequently consumed foods by elderly Thai patients in this study.

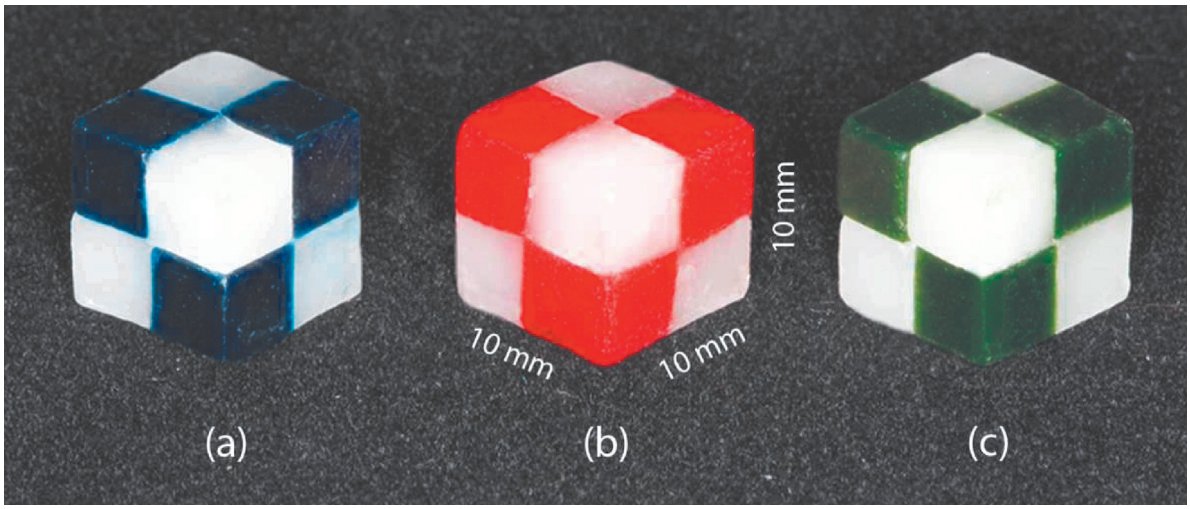

Fig. 1 *Size and shape of developed wax cube; (a) Hard wax cube, (b) Original wax cube, (c) Soft wax cube*

We measured the hardness levels of 10 pieces of each type of wax cube, and 10 pieces of each common food using a Universal Testing Machine (SHIMADZU EZTest®, SHIMADZU Corporation, Tokyo, Japan) under the following testing conditions:[26] (1) a circular plate 100 mm. in diameter was used for compressing the specimens, (2) the plate was set to compress the 10-mm. sample to 2.5 mm. (25% of its original height), and (3) the Universal Testing Machine cross-head speed was set at 10 mm./min. In this assay, the hardness score was the maximal peak force of the compression of the specimens.[26] The mean maximal peak force was calculated from the 10 pieces of each test item, and was used for statistical analyses of the hardness.

Subjects

The Ethics Committee of Chulalongkorn University approved all experimental procedures and tests. Each subject signed informed consent prior to the beginning of the study. The subjects of this study consisted of 3 groups selected to participate based on the following criteria: Group 1 was twenty subjects with normal dentitions (students and staff of Faculty of Dentistry) and consisted of 7 males and 13 females who had at least 1 premolar and 1 molar per quadrant (occluding pairs were counted as 2 occlusal units when one tooth in the upper arch occluded with one tooth in the lower arch) with a mean age of 27.85±1.42 years. Group 2 was composed of twenty totally edentulous subjects with complete dentures (routine follow-up patients of the Graduate Clinic, Department of Prosthodontics, Faculty of Dentistry, Chulalongkorn University), and consisted of 11 males and 9 females with a mean age of 70.55±9.14 years. Group 3 comprised twenty totally edentulous subjects with 2 standard implants in the lower arch for implant-retained lower complete dentures (routine follow-up patients of the Graduate Clinic, Department of Prosthodontics, Faculty of Dentistry, Chulalongkorn University), and consisted of 9 males and 11 females with a mean age of 67.70± 6.68 years. The subjects in groups 2 and 3 had been using their dentures for 1-3 months prior to this study. At the time of investigation, the dentures showed satisfactory stability and acceptable retention. The subjects were using their dentures regularly, during daytime and eating, and were considered to be well adapted to wearing dentures.

Chewing Ability evaluation

The wax cubes (10 mm. x 10 mm. x 10 mm.) were kept in an incubator (Contherm160M, Contherm Scientific Ltd., New Zealand) at 37 C for 24 hours, and then soaked in a water bath (Isotemp202, Fisher Scientific Co., Ltd, Japan) at 37°C for 10 minutes prior to testing. Each subject's chewing ability was evaluated in the same visit using the wax cubes with 3 levels of hardness in the order of hard, original, and soft.

Each subject sat in an upright position on the dental unit. The subject was instructed to chew three pieces of each type of wax cube, one cube after another for 10 chewing strokes, with their habitual chewing pattern. The chewed wax was removed from the oral cavity of the subject (Fig.2), rinsed under tap water for 20 seconds, and soaked in 70 percent ethyl alcohol for 5 minutes.

Fig. 2 *The chewed wax after 10 chewing strokes*

The images of both sides of the chewed wax were captured by a 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 the Image J program (Version 1.42Q, NIH, MD, USA). Using the original wax cube as an example, the standard color value that represented well mixed red and white wax was obtained by mixing an equal amount (by weight) of red wax and white wax until a uniform color of the mixture was observed. The Image J program was used for quantifying the observed color into a specific color value, ranging between 0 (white) to 255 (black).[24] The program also automatically output the number of color values, as well as the number of pixels, within a specified area. After the analyzing process, the Image J program showed that the standard color value of the original wax cube was in the range of 20-40.[24]

The chewing ability evaluation was done as follows: (1) the images of the chewed wax were analyzed using the measure function of the Image J program to find the total number of pixels of the images, (2) the images of the chewed wax were analyzed again using the color histogram function of the Image J program to define the number of pixels. The standard color values were output as a result, (3) 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.[24]

Each subject generated six surfaces (from three wax cubes) of the chewed wax for each type, therefore; the average value was calculated in order to determine the average "percentage of chewing ability" of each subject. We then interpreted the relationship between the hardness and the percentage of chewing ability.

Statistical analysis

Statistical analysis was performed with the Statistics Package for the Social Sciences (SPSS) version 17.0 (IBM Corporation, New York, USA). The means and the standard deviations (SD) of the percentage of chewing ability, the hardness score of the wax cubes and the selected common foods were analyzed. The two-way analysis of variance (ANOVA) and the Bonferroni multiple comparison tests were used for comparing the results of the three types of wax cube and three types of dentition. In the statistical analysis, a *p*-value less than .05 was considered significant.

Results

The developed wax cubes were used for evaluating the chewing ability of three different dentition groups by using the Image J program to analyze the color of the chewed wax. The average percentages of chewing ability (mean±s.d.) among the three groups of patients (patients with normal dentition group, patients with complete denture group, and patients with implant-retained lower complete denture group) from three types of wax cubes are shown in Table 1.

Table 1 *Mean and standard deviation of percentage of chewing ability obtained from three hardness of the wax cube*

Sample group	Type of chewing wax cube		
	Hard	Original	Soft
Normal Dentition	25.68±5.85	38.78±6.69 ***	42.17±9.08 ***
Complete Denture	21.89±5.82	26.00±7.33 *	27.68±6.04 **
Implant-retained Lower Complete Denture	21.28±5.30	33.30±5.66 **	34.73±3.25 ***

*: $p < .05$, **: $p < .01$, ***: $p < .001$

The results obtained from the original and the soft types of wax cubes showed that the normal dentition group had a higher percentage of chewing ability than the implant-retained lower complete denture group which was higher than the complete denture group. However, in testing the hard wax cubes, while the normal dentition group had a higher percentage of chewing ability than that of the complete denture and the implant-retained lower complete denture groups, the latter two groups result was similar.

The statistical analysis showed that the data was normally distributed with homogeneity of variance. The statistical analysis revealed a significant difference ($p < .05$) in percentage of chewing ability among the groups of dentition with only the original and the soft wax cubes.

The mean and the standard deviation of the hardness score (N) for each item are shown in Table 2. The mean hardness scores ranged from 1.30 N for the hard-boiled egg to 65.20 N for the fried pork. The hardness score of the hard wax cubes (63.55±2.49 N), the original wax cubes (50.80±2.15 N), and the soft wax cubes (41.59±4.56 N) were in the upper range of the selected common foods.

Table 2 *Mean and standard deviation of hardness scores for wax cubes and selected common foods*

No.	Item	mean±s.d. (N)
1	Hard-boiled egg	1.30±0.11
2	Boiled fish ball	2.52±0.80
3	Boiled pumpkin	2.70±0.60
4	Fried fish	4.16±1.60
5	Cooked jasmine rice	7.78±0.82
6	Plain omelet	9.61±0.49
7	Boiled cow-pea	11.83±3.27
8	Fresh guava	19.24±5.05
9	Boiled pork	20.80±3.30
10	Boiled baby corn	28.28±3.33
11	Boiled Chinese cabbage	30.98±3.63
12	Fresh apple	32.07±4.59
13	Fresh cow-pea	32.37±8.46
14	*Soft wax cube*	41.59±4.56
15	Boiled Chinese kale	47.44±5.24
16	*Original wax cube*	50.80±2.15
17	Fresh cucumber	51.04±3.75
18	*Hard wax cube*	63.55±2.49
19	Fried pork	65.20±2.85

Discussion

The results of this study indicate that the complete denture group had a lower chewing ability than the normal dentition group as assayed by the original and the soft wax cubes. In addition, the complete denture group had a lower percentage of chewing ability when chewing hard wax cubes compared to the original and the soft wax cubes. The loss of natural teeth is related to diminished nutritional intake, especially in older adults.[27] Studies have shown that the masticatory performance of edentulous patients with complete dentures is approximately 10-20 percent as efficient as dentate subjects.[18,28] In our study, an approximately 35 percent reduction in chewing ability was observed in the complete denture group when chewing the soft and the original wax cubes compared with the normal dentition group.

The implant-retained lower complete denture group showed a higher percentage of chewing ability than the complete dentures group for the original and the soft wax cubes. This indicates that edentulous patients with the implant-retained lower complete denture have a better chewing ability compared to the patients using conventional complete dentures when chewing the original and the soft wax cube. Geertman et al.[29] have reported that the edentulous subjects who had received two mandibular implants with overdentures rated their ability for chewing tough (steak) and hard (carrot) foods significantly better than the subjects who wore only conventional complete dentures. This may be attributed to the additional retention and the stability provided by implants and tissue support, while conventional dentures have only tissue support.

The sixteen common foods used in this study were selected from those most frequently consumed by patients we interviewed. The hardness test showed that almost all of the selected foods have a lower hardness than the three types of wax cube. From this we can conclude that the patients who are using conventional complete dentures can chew almost all of selected foods. However, they have a reduced ability to masticate them into fine particles compared to those with normal dentition. Among the selected foods, fresh fruits and raw vegetables can be difficult for denture-wearers to chew, but these problems can be overcome with proper food preparation.[30]

The results obtained from the hardness test shows that the hardness scores of the three types of wax cubes are in the upper range range of the selected common foods. However, the hard wax cube was too hard for all subjects to chew. The original and the soft wax cubes are the most suitable hardness for chewing ability evaluation in totally edentulous patients because the hardness score of only the original and soft wax cubes were within the range of suitable foods for totally edentulous patients.

Food texture is complex in nature, and is composed of mechanical, geometrical, and other perceived characteristics.[31] In our study, among the mechanical characteristics of food texture, only the hardness was evaluated. Other characteristics such as cohesiveness, toughness, and chewiness remain to be compared with other common foods in further study.

In conclusion, the development of two-colored wax cubes in Thailand has many advantages for chewing ability evaluation especially in totally edentulous patients. The results shown by percentages of chewing ability based on different harnesses of the wax cubes can enable clinicians to advise their totally edentulous or elderly patients to choose suitable foods according to their chewing abilities, and to select food items to meet the nutritional values as recommended for daily intake. The two-colored wax cube is an efficient tool for evaluating the chewing ability in 3-dimensions after denture delivery, however, both manufacturing and analyzing processes of this wax still need to be further developed, such as shortening the processes. In our study, only the use of complete dentures was evaluated among many factors of chewing ability. Other factors such as the type of edentulous ridge, the type of occlusal scheme, and the systemic disease of the subjects remain to be considered in future studies.

Conclusion

In the present study, we aimed to develop wax cubes with varieties of hardness for chewing ability assessment in totally edentulous patients with complete dentures, and to find the suitable hardness for those patients have chewing ability close to normal dentitions. We developed 3 types of hardness for the wax cubes and found that the original and the soft wax cubes are in the same range of hardness as common foods selected. Our results indicated that the original and soft wax cubes can be used to identify the chewing ability very well. Therefore, it is suggested that the original or soft type of two-colored wax cube can be one of the options for clinically screening chewing ability in the elderly patients.

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การพัฒนาความแข็งของชิ้นขี้ผึ้งเพื่อใช้ประเมินความสามารถในการบดเคี้ยว

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แหล่งเงินทุน: โครงการศูนย์ความเป็นเลิศทางการฟื้นฟูบูรณะช่องปากและใบหน้า

บทคัดย่อ

การศึกษานี้มีวัตถุประสงค์เพื่อพัฒนาความแข็งของชิ้นขี้ผึ้งเพื่อใช้ในการประเมินความสามารถในการบดเคี้ยวในผู้ป่วยไร้ฟันที่ใส่ฟันเทียมทั้งปากโดยกระบวนการที่สามารถทำได้ในประเทศไทย และเพื่อหาความแข็งที่เหมาะสมที่ผู้ป่วยจะมีความสามารถในการบดเคี้ยวใกล้เคียงกับผู้ที่มีฟันธรรมชาติ ชิ้นขี้ผึ้ง 3 ชนิด ได้แก่ ชนิดแข็ง ชนิดแรกเริ่ม และชนิดนิ่ม ถูกผลิตขึ้นโดยอัตราส่วนที่แตกต่างกันระหว่างไขผึ้งและขี้ผึ้งไมโครคริสตอลความแข็งของชิ้นขี้ผึ้งทั้ง 3 ชนิด และตัวอย่างอาหารทั่วไป 16 ชนิด ถูกทดสอบด้วยเครื่องทดสอบเอนกประสงค์ (SHIMADZU®) ผู้เข้าร่วมวิจัยประกอบด้วย กลุ่มฟันธรรมชาติจำนวน 20 คน (อายุเฉลี่ย 27.85± 1.42 ปี) กลุ่มฟันเทียมทั้งปากจำนวน 20 คน (อายุเฉลี่ย 70.55±9.14 ปี) และกลุ่มฟันเทียมล่างทับรากเทียมจำนวน 20 คน (อายุเฉลี่ย 67.70±6.68 ปี) ให้ผู้เข้าร่วมวิจัยเคี้ยวชิ้นขี้ผึ้ง 3 ชนิด ชนิดละ 3 ชิ้น ครั้งละชิ้น ๆ ละ 10 ครั้ง ในตำแหน่งที่ถนัด นำชิ้นขี้ผึ้งที่ผ่านการเคี้ยวแล้วไปถ่ายภาพและ วิเคราะห์ความสามารถในการบดเคี้ยวด้วยโปรแกรมอิมเมจเจ ที่คำนวณ ร้อยละของสีที่ผสมกันได้ดี จากสถิติวิเคราะห์พบว่า มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติของร้อยละของความสามารถในการบดเคี้ยว ($p < .05$) ระหว่างกลุ่มฟันธรรมชาติ กลุ่มฟันเทียมทั้งปาก และกลุ่มฟันเทียมล่างทับรากเทียม เฉพาะในการเคี้ยวชิ้นขี้ผึ้งชนิดแรกเริ่มและชนิดนิ่มเท่านั้น กลุ่มฟันเทียมทั้งปากมีความสามารถในการ บดเคี้ยวขี้ผึ้งชนิดแรกเริ่มและชนิดนิ่มลดลงประมาณร้อยละ 35 เมื่อเปรียบเทียบกับกลุ่มฟันธรรมชาติ กลุ่มฟันเทียมล่างทับรากเทียมมีความสามารถในการบดเคี้ยวสูงกว่ากลุ่มฟันเทียมทั้งปาก จากการศึกษาพบว่า ความแข็งของชิ้นขี้ผึ้งที่เหมาะสมในการประเมินความสามารถในการบดเคี้ยวในผู้ป่วยไร้ฟันที่ใส่ ฟันเทียมทั้งปาก คือ ชิ้นขี้ผึ้งชนิดแรกเริ่มและชนิดนิ่ม และชิ้นขี้ผึ้งทั้งสองอยู่ในช่วงความแข็งของตัวอย่าง อาหารที่เลือกมาทดสอบ ชิ้นขี้ผึ้งชนิดแข็งมีความแข็งมากเกินกว่าที่จะเคี้ยวได้การศึกษานี้แนะนำว่าชิ้นขี้ผึ้งเป็นอีกทางเลือกหนึ่งที่สามารถนำมาใช้ในการคัดกรองความสามารถในการบดเคี้ยวร่วมกับเครื่องมืออื่น ๆ ในการประเมินสภาวะโภชนาการของผู้สูงอายุได้