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Influence of palatal surface shape of dentures on food perception

Author(s)
Tanaka, A; Kodaira, Y; Ishizaki, K; Sakurai, K

Journal
Journal of oral rehabilitation, 35(10): 715-721

URL
http://hdl.handle.net/10130/1103

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Aya Tanaka, Yorika Kodaira, Ken Ishizaki & Kaoru Sakurai

Keywords: food perception, ingestion, denture base, surface shape, palate

Correspondence: Aya Tanaka
Department of Removable Prosthodontics and Gerodontology, Tokyo Dental College, 1-2-2 Masago, Mihama-ku, Chiba city, Chiba, 261-8502, Japan
Phone: +81-43-270-3933/ Fax: +81-43-270-3935
E-mail address: atanaka@tdc.ac.jp
Abstract

The purpose of this study was to clarify the influence of the palatal surface shape of dentures on food perception. Eighteen healthy dentulous subjects (mean age, 24 years) were investigated. Four types of experimental plate were used: i) a Tailor-made plate, ii) an Average-model plate, iii) a Smooth plate, and iv) a Wrinkle plate. Test foods consisted of Bavarian cream cubes containing 1-3 mustard seeds and 6 raw carrot pieces of different shapes. The Bavarian cream cubes with 3 seeds were used for analysis. The other foods were used as dummy foods.

Subjects were required to wear experimental plates and press test foods placed on the anterior area of the tongue against the experimental plates. We measured time required to perceive number of spherical bodies, rate of correct answers, and level of perception with each type of experimental plate using a 100-mm visual analogue scale. The results showed a significant difference in response time between the Average-model plate and the other experimental plates, with response time longest for the Average-model plate. On the other hand, no significant differences in rate of correct answers regarding number of spherical bodies or level of perception were found among the experimental plates. When incisive papilla, palatine suture and palatal rugae based on the standard Japanese shape were replicated on the palatal surface of the plates, the time required for food perception during ingestion was prolonged in comparison to plates with other palatal surface shapes.
Introduction

When complete dentures are applied to the maxilla, the palatal mucosa should be covered with a denture base to obtain denture retention and support. A number of studies have investigated the influence of denture palatal coverage on oral function. It was found that palatal coverage impaired perception of size of intra-oral spherical bodies (1) and taste (2). Furthermore, in terms of swallowing, it has been reported that palatal coverage affects bolus-propulsion time, and particularly coverage of the posterior hard palate (3). No studies have found that palatal coverage improved oral function.

A number of reports have compared influence on oral function between dentures with and without palatal surface shape (smooth dentures). According to those reports, pronunciation was improved by shaping incisive papilla and a palatal rugae-like shape on the palatal surface of dentures (4), and by roughing the denture’s anterior palatal surface (5), compared with smooth dentures. Furthermore, it has been reported that the palatal surface shape of the denture is related to improvement in taste perception (6), that and the tip of the tongue can be maintained in a normal position during swallowing by wearing dentures in which individual palatal mucosal shape has been reproduced on the denture’s palatal surface (7). Although there have been many reports on the influence of palatal coverage and area of coverage on intra-oral function to the authors’ knowledge, no studies have investigated the relationship between palatal surface shape of dentures and food
perception. Furthermore, the selection criteria for the shape of the denture’s palatal surfaces are vague, with shape selection dependent on the dentist’s clinical experience alone. It has been reported that humans perceive food by pressing it against the palate with the tongue during food ingestion (8). Therefore, covering the palate with dentures influences the perception of food texture.

In addition, the representative materials used in previous studies on oral perception for evaluating shape perception have included plastics (9), metal alloy (10), and acrylic resin (11–14). On the other hand, raw carrot has also been used as a representative food material (15). There are few studies, however, on oral perception using food as a test material.

In this study, we hypothesized that the denture’s palatal surface plays an important role in perception of food texture. The purpose of this study was to clarify the influence of the palatal surface shape of dentures on food perception.

Materials and Methods

Subjects

Eighteen healthy dentulous subjects (12 men and 6 women, range 20-30 years, mean age; 24 years) were investigated. Written, informed consent was obtained from all subjects. Three of the subjects who had an abnormal swallowing habit (16) or a present or previous history of wearing dentures or orthodontic appliances were excluded from the study.
**Experimental Ethics**

The study was approved by the Ethics Committee of Tokyo Dental College (#116). All experiments were performed in accordance with the Edinburgh Revision of the Helsinki Declaration.

**Experimental plates**

The following 4 types of experimental plate were established: (i) a Tailor-made plate, configured from an individual dental cast according to the method of Garfunkel et al (17); (ii) an Average-model plate, with incisive papilla, palatine suture, and palatal rugae based on the standard shape in the Japanese population (18); (iii) a Smooth plate, with a smooth surface; (iv) and a Wrinkle plate, in which the palatal surface was finely corrugated using stippled sheet wax. Experimental plates were produced using heat curing acrylic resin. The thickness of each experimental plate was 1.5 mm, and the posterior border was set on the vibrating line (Fig. 1).

**Test foods**

Test foods consisted of Bavarian cream cubes¹ (length, 15 mm; weight, about 2.2 g; temperature, 22°C) containing 1, 2 or 3 mustard seeds, each, and 6 raw carrot pieces of different shapes (all cut from a section with a maximum length of 15 mm and a thickness of 5 mm). Among these test foods, only the Bavarian cream cubes with 3 mustard seeds were analyzed (analytical test
foods), and the other foods were used to avoid adaptation concerning perception of number of spherical bodies (dummy foods) (Fig. 2). The Bavarian cube consisted of Bavarian powder, hot water, dairy cream and milk. Bavarian powder was dissolved in hot water, and mixed with dairy cream and milk. This mixture was poured into the mold (length, 15 mm), and the mustard seeds were placed inside the Bavarian cream cubes before they set. The hardness of the Bavarian cream cubes was $54 \times 10^3$ Kg (determined by compressing at up to 90% strain at a constant speed of 1.0 mm·s$^{-1}$, using a cylinder probe 12.7 mm in diameter). The diameter of the mustard seeds used for the experiments was set to 2.03-2.36 mm, taking into account the two-point discrimination threshold at the tongue tip (19, 20). Therefore, the diameter of the mustard seeds was set to be greater than that of the two-point discrimination threshold. Sieves were used for selecting the mustard seeds: mustard seeds passing through a sieve with a 2.36 mm pore size were placed on a 2.02-mm pore size sieve, and mustard seeds which did not pass through were used in the test foods.

In this study, the mustard seeds were placed inside Bavarian cream cubes to prevent direct contact between mustard seeds and tongue prior to measurement. We used Bavarian cream cubes, as they are firm in texture but may be crushed by pressure from the tongue.

**Process of experiments**

The test foods were placed on the anterior area of the tongue, with the subjects wearing experimental
plates and keeping their eyes closed and mouths open. The subjects were required to perform food perception for each test food using their tongue and experimental plate on a signal from the researcher. Subjects had to count the number of spherical bodies in the Bavarian cream cubes. They were instructed to crush the test foods with the tongue and perceive the number of contained mustard seeds. The subjects then reported the number of spherical bodies perceived. Furthermore, the subjects were required to perceive the shape of the punched-out carrot pieces. After completing shape perception, the subjects were shown a chart with drawings of the raw carrot pieces used for test foods. They had to select which drawing matched the shape perceived. The subjects were asked to perform the food perception task as quickly as possible. Furthermore, during test food perception, the subjects were not allowed to bite the test foods or push them against the lips and buccal mucosa. After completing each perception, the subjects gargled. This process was performed using one type of experimental plate per day, with each of the 4 types of experimental plate being applied every other day. The order of the use of the 4 types of experimental plate and test foods was determined by the randomized block method. Perception was performed a total of 31 times per type of experimental plate: 10 times for analytical test food, 7 times for spherical bodies in test food containing 2 mustard seeds, 9 times for spherical bodies in test food containing 1 mustard seed, and 5 times for carrot shape.

Measurement tasks
1. Response time

Response time was set as the time between the subject’s initiation of perception on a signal from the researcher and the subject’s judgment at the completion of perception. To confirm that the subjects were perceiving test foods, tongue movement during food perception was simultaneously observed by monitoring muscle activity in the area corresponding to the mylohyoid muscle using an electromyograph (21).

2. Rate of correct answers

Rate of correct answers was determined based on number of Bavarian cream cubes with 3 mustard seeds correctly perceived per 10 analytical test foods.

3. Level of perception

Level of perception for number of spherical bodies with each experimental plate was measured using a 100-mm visual analogue scale (VAS). The VAS score was 0 when perception was difficult and 100 when it was easy.

Statistical analysis

The data for response time, rate of correct answers, and level of perception for the various experimental plates were statistically analyzed with a one-way repeated measures ANOVA. After the one-way repeated measures ANOVA, the multiple comparison (Bonferroni test) post hoc test was
performed at a significance level of $\alpha = 0.05$. All analyses were performed with SPSS for Windows 11.

SHOFU INC., Kyoto, Japan.

Acron, GC Co., Tokyo, Japan.

Bavaroria, Inashyokuhin, Tochigi, Japan.

** Mega Win version 2.3, MP Japan, Tokyo, Japan.

‡‡ SPSS11.0J (SPSS Inc., Chicago, IL, USA)

Results

Mean response time was $7.4 \pm 3.3$ sec with the Average-model plate, $6.0 \pm 2.3$ sec with the Smooth surface plate, $6.0 \pm 2.2$ sec with the Tailor-made plate, and $5.7 \pm 2.5$ sec with the Wrinkle plate. Significant differences were indicated between the Average-model plate and Smooth surface plate ($P=0.042$), Average-model plate and Tailor-made plate ($P=0.034$), and Average-model plate and Wrinkle plate ($P=0.006$). Mean response time was longest with the Average-model plate (Fig. 3).

The rate of correct answers during food perception was $34.7 \pm 27.3\%$ with the Tailor-made plate, $29.6 \pm 26.4\%$ with the Smooth surface plate, $28.1 \pm 2.4\%$ with the Wrinkle plate, and $23.0 \pm 15.8\%$ with the Average-model plate, showing no significant differences among the experimental
plates (Fig. 4).

Level of perception was 42.6 ± 23.8 with the Average-model plate, 54.7 ± 22.9 with the Tailor-made plate, 41.1 ± 23.8 with the Smooth surface plate, and 57.0 ± 20.5 with the Wrinkle plates, showing no significant differences among the experimental plates (Fig. 5).

Discussion

The purpose of this study was to clarify the influence of differences in palatal surface shape of dentures on food perception during food ingestion. The results showed that palatal surface shape influenced time taken to perceive food texture. Usually, dentulous persons extra-orally determine food texture using their eyes, hands and fingers, going on to establish further details of food texture with their lips, buccal mucosa, periodontal ligaments, tongue and palatal mucosa. During the early stage of the preparatory stage, in particular, at immediately after ingestion but before mastication, food texture perception is mainly achieved while pressing foods against the palatal area using the tongue (8).

However, in the case of complete denture wearers, food texture perception is chiefly achieved via sensation on the tongue, as dentures cover the palate, blocking the function of its mechanoreceptors. The surface of the palatal mucosa is not smooth due to various anatomical features such as incisive papilla, palatine suture, and palatal rugae, and food perception is performed by pressing food against the palatal mucosa during food ingestion. This suggests that the shape of the palatal area is an
important factor in perceiving the physical properties of foods, and that difference in palatal surface shape influences the perception of shape, physical properties, and amount of foods.

In this study, we used foods as the test materials. The use of materials other than foods is advantageous, in that the size and hardness of the materials used for perception can be kept constant, and the physical properties uniform. On the other hand, food materials are advantageous, in that foreign body-like sensation is weaker than with non-food materials, and experiments can be performed under conditions similar to normal ingestion. Therefore, foods were used as the test materials in this study. Humans investigate food properties using the palatal mucosa and tongue during ingestion, and masticate to determine whether bolus-formation is necessary (8). Therefore, test foods comprised of seeds Bavarian cream cubes containing seeds were used in this experiment to provide food materials with different physical properties.

In this study, 4 types of palatal plate which are clinically applied to the palatal surface of metal plates and resin plate dentures were used (22–25). In general practice, the palatal surface of a denture is sometimes shaped according to the contours of the palatal rugae, palatine suture and incisive papilla. Therefore, we used a custom-designed Average-model plate, which is not a model often used in Japan, but a standard model produced for this study, based on averages of the palatal rugae, incisive papilla, and palatine suture sizes in Japanese. Therefore, the shaping of the denture’s palatal surface will depend on the dentist’s clinical experience. If there are additional features in the palatal surface,
they vary with dentists. Therefore, to obtain evidence, we conducted this study. No palatal coverage as a control was not used, as our purpose was to investigate the influence of palatal surface shape of dentures for complete denture wearers. The results showed that, among the 4 types of palatal plate, food response time was longest with the Average-model plate. In 1979, Palmer reported that the shaping of incisive papilla and a palatal rugae-like shape on a denture’s palatal surface improved speech (4). However, our results showed that when the shape of the incisive papilla, palatine suture and palatal rugae on the denture’s palatal surface differed from that of the individual food perception became difficult. We believe that the difference in palatal surface shape between the Average-model plate and the shape of the palatal mucosa of the individual, along with a lack of fine concavo-convexity on the surface, caused the subjects to experience discomfort in the oral cavity during food perception. This discomfort may have led to inhibition of smooth movement of the tongue, which is very important during perception, and so food perception required more time.

The Average-model plate yielded prolonged response time and a lower score for counting number of spherical bodies than the other experimental plates. The results showed significant but rather small differences in response time between the Average-model plate and the others. Some studies found that muscle force and coordination in the oral cavity decreased with age (26), and that tongue pressure necessary for food perception also decreased with age (27). This suggests that the actions involved in perception slow with age, resulting in prolonged food response time in elderly
persons. Therefore, our results suggest that it is important to consider palatal surface shape during production of dentures for the elderly.

We believe another reason for this was that the shape of the mustard seeds was similar to that of the incisive papilla replicated on the Average-model plates. Furthermore, no significant differences in response time were found among the Tailor-made plates, Smooth plates, and Wrinkle plates. We believe this was because the degree of concavo-convexity was smaller or none in these plates than in the Average-model plate.

On the other hand, although a significant difference was found in response time, no significant differences were detected in the rate of correct answers and VAS scores. It is speculated that the rate of correct answers did not show any significant differences among the experimental plates, as the time required to perceive the number of spherical bodies was set as the time until the completion of judgment. As a significant difference in response time was exhibited, we speculated that if a time limit had been set for food perception, the rate of correct answers would have shown significant differences among the 4 types of experimental plate. However, no time limit was set for food perception. It was difficult to set the criteria for time limit, as the time required to perceive food is not the same for all subjects. VAS scores, which were obtained from subjective evaluation, showed no significant differences among the experimental plates. We believe that this was because the subjects were young dentulous persons with no history of previous denture use, and because the discomfort of the
Experimental plates themselves outweighed the influence of differences in experimental plate; therefore, no significant differences among experimental plates were detected.

Experimental plates were worn for one hour before the initiation of experiments to obtain a regular salivary flow and plate temperature during the experiment. This study did not investigate the effects of prolonged wear over a period of several weeks or months. Therefore, it is uncertain as to whether the results obtained in this study would be the same as those in patients wearing dentures over a long period, as the effects of adaptation were not taken into account. A study by Ikebe et al. showed that there was no significant difference in oral stereognosis between fully dentate persons and complete denture wearers. This was thought to be the result of the habituation process (28). They suggested that acclimatization would make no significant difference. However, some reports have shown that muscle coordination in the oral cavity decreases with age (26). It appears that it takes more time for elderly denture wearers to adapt to new dentures. This suggests that, considering the results obtained in this study, it is necessary to design dentures that will enable wearers to perceive food well and adapt easily.

The results of this study showed that there was no difference in time required for food perception during ingestion among Smooth plate, Wrinkle plate and Tailor-made plate (configured from an individual dental cast). However, when incisive papilla, palatine suture, and palatal rugae based on the standard Japanese shape were replicated on the palatal surface of dentures, the time
required for food perception during ingestion was prolonged. This suggests that use of the standard
Japanese model hinders food perception and adaptation, causing discomfort for denture wearers,
especially in the elderly. Dentists should, therefore, recommend the use of Tailor-made dentures.
However, further study is required to determine whether these results would be affected by other types
of denture material, adaptation, or differences in typical racial palatal shape.

Acknowledgments

We are grateful to the subjects for their kind cooperation in this study. We also thank
Dr Mutsumi Takagiwa (Associate Professor, Mathematics Laboratory, Tokyo Dental College) for his
instruction on statistical analysis and Jeremy Williams (Associate Professor, Laboratory of
International Dental Information, Tokyo Dental College) for his assistance in editing the language
(English) of this manuscript. This work was supported by a grant from the Promotion and Mutual
Aid Corporation for Private Schools of Japan.

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**Figure Legends**

Fig.1 Types of experimental plate

1a, Tailor-made plate; 1b, Average-model plate; 1c, Smooth plate; 1d, Wrinkle plate

Fig.2 Test foods

Fig.3 Comparison of response time with each experimental plate

TMP, Tailor-made plate; AMP, Average-model plate; SP, Smooth plate; WP, Wrinkle plate

Fig.4 Comparison of rate of correct answers with each experimental plate

TMP, Tailor-made plate; AMP, Average-model plate; SP, Smooth plate; WP, Wrinkle plate

Fig.5 Comparison of degree of perceptibility of number of spherical bodies with each experimental plate

TMP, Tailor-made plate; AMP, Average-model plate; SP, Smooth plate; WP, Wrinkle plate
Fig. 1
<table>
<thead>
<tr>
<th>Shape</th>
<th>Material</th>
<th>Matters for investigation</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
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<td>Bavarian cream &amp; Mustard seeds</td>
<td>Counting number of mustard seeds</td>
<td>analytical test foods</td>
</tr>
<tr>
<td><img src="image" alt="Four Cubes" /></td>
<td>Bavarian cream &amp; Mustard seed(s)</td>
<td>Counting number of mustard seed(s)</td>
<td>dummy foods</td>
</tr>
<tr>
<td><img src="image" alt="Diagrams of various shapes" /></td>
<td>Raw carrots</td>
<td>Distinguishing shape</td>
<td>dummy foods</td>
</tr>
</tbody>
</table>

Fig. 2
Fig. 3

Respons time (sec)

AMP

Type of experimental plate

P < 0.05

*: SD
Fig. 4

Type of experimental plate

Rate of correct answers (%)
Degree of perceptibility (VAS score)

Type of experimental plate

Fig. 5