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Impacts of palatal coverage on bolus formation during mastication and swallowing and subsequent adaptive changes

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SUMMARY Palatal coverage is often required for elderly edentulous patients with complete dentures. The purpose of this study was to clarify impacts of palatal coverage on bolus formation and subsequent adaptive changes. Subjects were 18 healthy young dentulous adults who wore 1·5-mm-thick palatal plates. Subjects were asked to feed 12 g of bicoloured rice as usual, and the bolus formation by mastication and swallowing in the pharynx was observed using a nasal videoendoscopy. The bolus formation index (BFI), number of mastication strokes until swallowing, visual analogue scale about swallowing easiness and masticatory performance using colour-changeable gum were measured under three conditions: before placement of the palatal plate (day 0), immediately after placement (day 1) and after 7 days of wearing the plate (day 7). BFI and visual analogue scale on day 1 were significantly lower than those on day 0, but those on day 7 significantly recovered to the level of day 0. The number of mastication strokes did not change from day 0 to day 1, however, that on day 7 was significantly higher. Masticatory performance on days 1 and 7 was significantly lower than that on day 0. Although palatal coverage inhibits bolus formation during feeding, subjects increased the number of mastication strokes until swallowing threshold as they adapted to palatal coverage over time. This adaptive change was due to compensate for the lowered masticatory performance to achieve bolus formation for comfortable swallowing.

KEYWORDS: denture, palate, adaptation, mastication, deglutition, endoscopy

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Background

Palatal coverage is the most common form of upper complete dentures that were used for considerable number of elderly people (1). Full palatal coverage is commonly performed to gain stability and retention of upper complete dentures, but is unnecessary if dentures have additional retention from implant placements and subsequent locator attachments. Both dentists and patients know that dentures without palatal coverage might result in more comfortable feeding (2). Roles of the palate during mastication are to work in cooperation with the tongue to comminute and mix the food with saliva to form the food into a bolus. Palate sensation during mastication may help to control masticatory movements. Moreover, when it is perceived that the bolus is swallowable, the tongue transport the bolus to aggregate into the pharynx (3). The palate also acts as an anchor for tongue movement to produce pressure during swallowing reflex. Thus, the palate is strongly involved in bolus formation and transportation during mastication and swallowing. Therefore, it is necessary to consider the impacts of palatal coverage on masticatory and swallowing function.

Previous studies revealed negative impacts of palatal coverage (4–7). However, these previous studies

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regarded mastication and swallowing as separate functions, and no studies have assessed masticatory function involving the perspective of swallowing. In other words, almost masticatory evaluations were performed without swallowing. Several recent studies used videofluorography to comprehensively evaluate mastication and swallowing, suggesting that mastication may directly affect swallowing (8). Furthermore, insufficient bolus formation by reduced masticatory function may increase the risk of pharyngeal swallowing disorders (9, 10). It is thus important to consider how well formed the bolus must be to allow it to be smoothly swallowed.

Other recent endoscopic studies evaluated bolus formation by mastication for swallowing (11–13). An advantage of endoscopic evaluation of masticatory function is that the bolus formation by mastication can be qualitatively and quantitatively assessed during a sequence of natural feeding. However, the impacts of palatal coverage on bolus formation by mastication and on subsequent swallowing are largely unknown. It is likely that the use of palatal coverage will continue to increase, especially for frail elderly individuals and elderly individuals requiring care (1). These patients are prone to poor masticatory and swallowing functions (14) and little functional reserve capacity. Although a thorough understanding of the possible changes that may arise in masticatory and swallowing functions after palatal coverage is very important for prosthetic treatment for the elderly population, there is no evidence of relationships among bolus formation, swallowing and palatal coverage. To address those issues, the present study evaluated impacts of palatal coverage on bolus formation during natural feeding using endoscopy, focusing on subsequent temporal changes in masticatory and swallowing function.

Methods

Subjects

The subjects were 18 healthy dentulous adults (11 men and 7 women; mean age, $28{\cdot}2 \pm 1{\cdot}6$ years) without masticatory or swallowing dysfunction. This study was approved by the Ethics Committee of Iwate Medical University, School of Dentistry (Approval No. 01148). Written informed consent was obtained from each subject. A certain degree of reproducibility in the number of mastication until swallowing threshold was confirmed prior to the experiment.

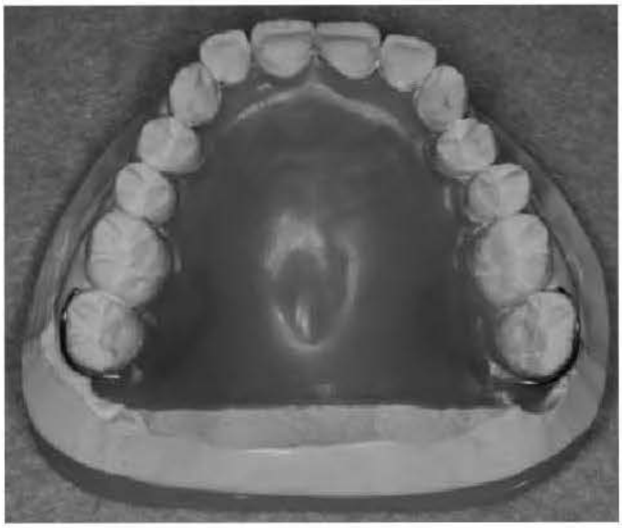

Fig. 1. Wax-up of the experimental palatal plate. The wax was subsequently substituted with the denture resin according to the conventional denture processing technique. The plate covered the entire palate as well as full palatal coverage of upper complete denture. The final thickness of the plate was 1·5 mm.

Fabrication of the experimental palatal plates

Working casts were fabricated from impressions of the upper and lower jaws each subject. An experimental palatal plate identical to the upper complete dentures was waxed up (Fig. 1). Cobalt–chrome wire clasps (0·9 mm) were used for the second molars to reinforce the fit. The wax patterns were substituted by denture base hard resin using conventional methods, resulting in the thickness of the palatal area was 1·5 mm. The experimental palatal plates were then delivered to the subjects and adjusted to fit adequately.

Endoscopic evaluation of bolus formation ability

Endoscopic evaluation of bolus formation ability in this study was performed using the methods of Abe *et al.* (13). The videoendoscopic system comprised a nasopharyngeal fibrescope (ENF-P4;*), video system (OTV-SI;*), video recorder (GV-HD700;†), microphone, microphone mixer and colour monitor. Each subject was examined

*Olympus, Tokyo, Japan
†SONY, Tokyo, Japan.

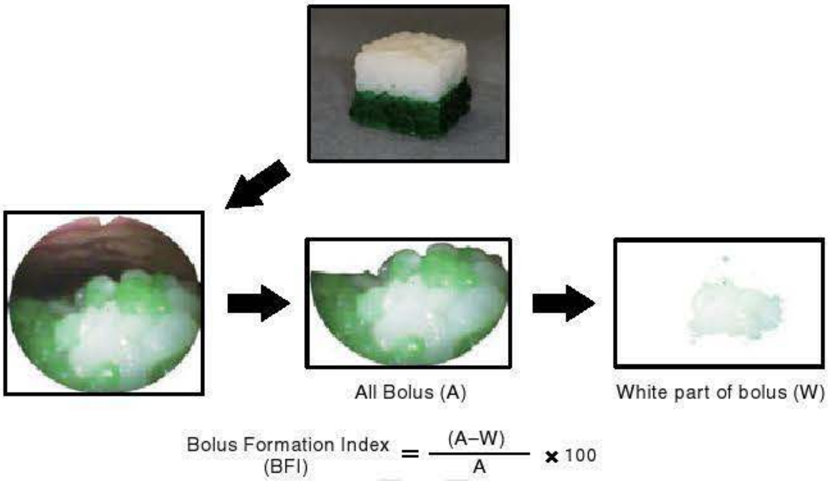

Fig. 2. Measurement of the bolus formation index (BFI) (13). First, the area of the entire bolus (A) on the endoscopic image was measured in terms of pixels. The area of the white part (W) of the bolus was then measured in terms of pixels. The area of mixed white and green parts was calculated as (A−W) in pixels, and its proportion to the area of the entire bolus was obtained as the BFI.

in an upright sitting position with the head adjusted by a headrest. In accordance with the protocol of fibreoptic endoscopic evaluation of swallowing, the endoscope was inserted through the nose and set in a high position as steadily as possible (15). The test food was bicoloured cooked rice (white and green) formed into 2- × 2- × 2-cm cubes that weighed 12 g to facilitate observation the bolus formation. Subjects were requested to place the test food on their tongue and feed as usual; the number of mastication strokes and timing of swallowing was not restricted. The endoscopic videos were recorded on a computer, and the bolus formation index (BFI) was calculated from endoscopic images of the bolus just before swallowing using the methods of Abe *et al.* (13). As the white- and green-coloured rice was mixed by mastication, the white part disappeared. Therefore, better bolus formation resulted in a higher BFI. Measurements were performed using image measurement software (Photoshop CS5 Extended;[‡]) (Fig. 2).

Number of masticatory strokes until swallowing threshold

Simultaneously with endoscopic measurement, a surface electromyogram (EMG) was taken by attaching Ag/AgAl electrodes (F-150M;[§]) to the masseter muscles on each side at an interelectrode distance of 20 mm. The EMG output was amplified by an EMG amplifier (EMG-021;[¶]) and converted with an analogue digital converter (PowerLab ML880;**). A single EMG burst of the masseter muscles was considered to be one mastication stroke, and the number of masticatory strokes was measured from chewing onset to the swallowing threshold (16).

Subjective evaluation of swallowing easiness

A visual analogue scale (VAS) was used to evaluate how easy subjects feel with pharyngeal swallowing. The VAS was a 100-mm-long horizontal line, and the left side represented 'the most difficult to swallow' (0 mm) and the right side represented 'the easiest to swallow' (100 mm). Subjects were asked to mark on the scale immediately after each feeding.

Masticatory performance evaluation using colour-changeable gum

Using colour-changeable gum is a convenient method to evaluate masticatory performance in fixed masticatory strokes (17). In the present study, subjects were given the chewing gum (Masticatory Performance Evaluating Gum XYLITOL;[††]) to allow for the assessment of masticatory performance during 60 normal masticatory strokes. Then, according to the methods used by Komagamine *et al.* (17), a colorimeter (CR-13;[‡‡]) was used to measure L^*, a^* and b^* values. Masticatory performance was represented by the colour difference (delta E; ΔE) between the chewed and unchewed specimen that ($L^* = 72{\cdot}3$, $a^* = -14{\cdot}9$,

[‡]Adobe Systems, Tokyo, Japan.
[§]Nihon Kohden, Tokyo, Japan.
[¶]Harada Electronic Industry, Sapporo, Japan.
**ADInstruments Japan, Tokyo, Japan.
[††]Lotte, Tokyo, Japan.
[‡‡]KONICA MINOLTA, Tokyo, Japan.

b^* = 33·0) to reveal how efficiently the subjects could mix the gum.

Measurement days and statistical analysis

All evaluations were measured on three measurement days as follows: before placement of the palatal plate (day 0, set as the baseline), immediately after placement (day 1) and after 7 days of wearing the plate (day 7). The experiment was performed in three times for each condition. Subjects were instructed to wear the palatal plate during the experimental periods after the measurement at day 1. They wore the plate all day including when eating, drinking and speaking except while asleep.

Statistical analysis was performed using statistical software (SPSS ver. 20;[§§]), and the level of significance was set at 5%. A one-way analysis of variance for repeated measurements and multiple comparisons using Tukey's method were performed to analyse differences in values among the measurement days.

Results

The BFI on day 1 was lower than on day 0 ($P < 0{\cdot}001$), and the declined BFI significantly recovered to the original level on day 7 ($P < 0{\cdot}001$). There was no significant difference between days 0 and 7 ($P = 0{\cdot}697$) (Fig. 3). In a box and whisker plot, the lower and upper quartile, median, whiskers and outliners were defined as follows; the lower and upper quartile are the first and third quartile, respectively; the median is second quartile; the upper and lower whisker are the highest and lowest data still within 1·5 times the length of interquartile range (box length), respectively. In addition, the data deviated more than the whiskers were treated as the outliners.

The number of mastication strokes until the swallowing threshold showed no significant change from day 0 until day 1 ($P = 0{\cdot}403$). However, the number of strokes on day 7 was significantly higher than that on days 0 and 1 ($P = 0{\cdot}001$ and 0·025, respectively) (Fig. 4).

The VAS score of swallowing easiness was lower on day 1 than on day 0 ($P < 0{\cdot}001$), then it significantly recovered to the original level on day 7 ($P < 0{\cdot}001$).

[§§]IBM Japan, Tokyo, Japan.

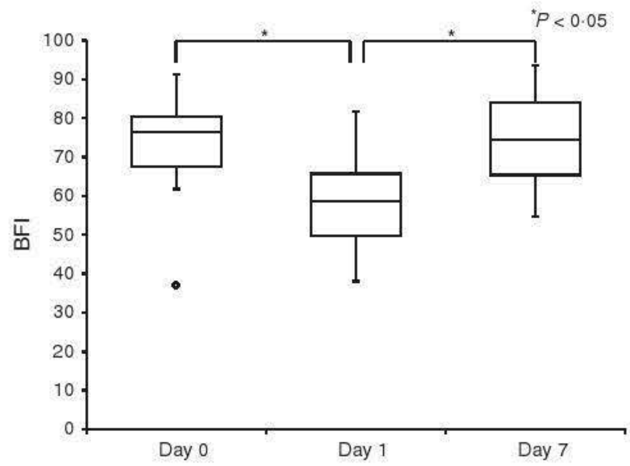

Fig. 3. Temporal changes in bolus formation index (BFI) (*$P < 0{\cdot}05$). Vertical axis indicates the value of the BFI. The BFI was significantly lower on day 1 than on day 0 ($P < 0{\cdot}001$). The BFI on day 7 recovered significantly to the original level of day 0 ($P < 0{\cdot}001$). There was no significant difference between days 0 and 7 ($P = 0{\cdot}697$). The box consists of first quartile, median and third quartile. Whiskers are minimum and maximum values. The circle indicates an outliner that deviates from 1·5 times the length of interquartile range.

There was no significant difference between days 0 and 7 ($P = 0{\cdot}131$) (Fig. 5).

The masticatory performance (ΔE) on days 1 and 7 was lower than that on day 0 ($P = 0{\cdot}034$ and 0·039, respectively), and there was no significant change between days 1 and 7 ($P = 0{\cdot}998$) (Fig. 6).

Discussion

The most important role of mastication is to form a swallowable bolus for smooth swallowing, and impacts of palatal coverage on bolus formation and subsequent adaptive changes were examined in this study. The results show that palatal coverage reduces bolus formation ability and masticatory performance and makes swallowing more difficult. However, the reduction in bolus formation due to palatal coverage was recovered to the original level until 7 days as subjects adapted to feed with palatal coverage, resulting in swallowing difficulty was also alleviated. In contrast, masticatory performance (ΔE) was not recovered despite subjects wore the plate for 7 days. Consequently, subjects learned to increase the number of mastication strokes to form an easy swallowable bolus, compensating for reduced masticatory performance by palatal coverage.

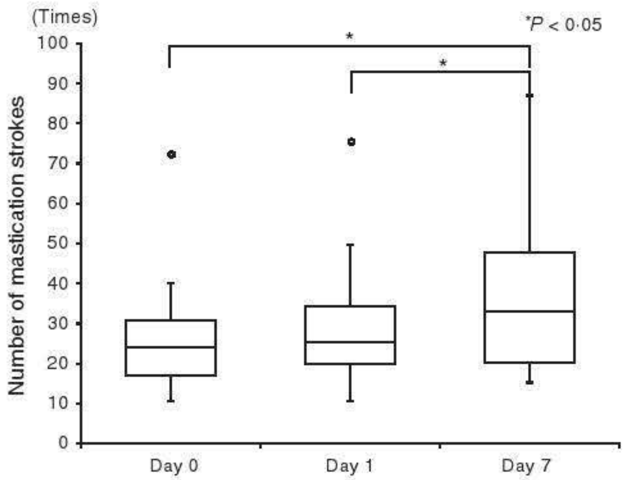

Fig. 4. Temporal changes in the number of mastication strokes until the swallowing threshold (*$P < 0{\cdot}05$). Vertical axis indicates the number of mastication strokes until the swallowing threshold. No significant changes were observed between days 0 and 1 ($P = 0{\cdot}403$). The number of strokes on day 7 was significantly higher than that on days 0 and 1 ($P = 0{\cdot}001$ and 0·025, respectively). The box consists of first quartile, median and third quartile. Whiskers are minimum and maximum values. Circles indicates outliners that deviate from 1·5 times the length of interquartile range.

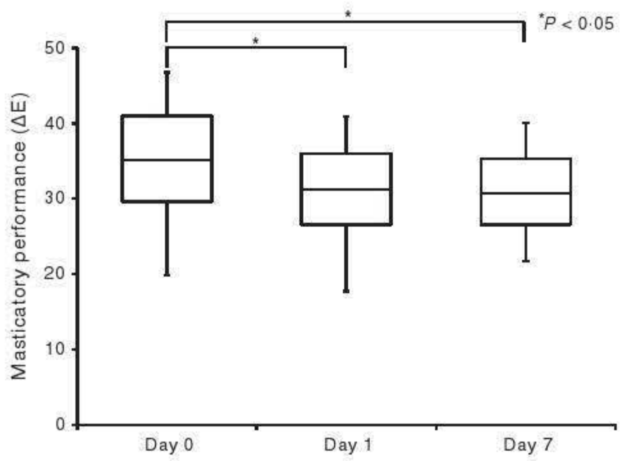

Fig. 6. Temporal changes in masticatory performance (ΔE) (*$P < 0{\cdot}05$). Vertical axis indicates the colour difference between the chewed and unchewed specimen. A large colour difference showed a high masticatory performance. The ΔE was significantly lower on days 1 and 7 than on day 0 ($P = 0{\cdot}034$ and 0·039, respectively). There was no significant difference between days 1 and 7 ($P = 0{\cdot}998$). The box consists of first quartile, median and third quartile. Whiskers are minimum and maximum values.

A possible explanation of reductions in BFI and ΔE is that wearing the plate blocked palate sensation (18) and altered the anatomical shape of the oral cavity, impairing the tongue movement during mastication (6, 7). After wearing the palatal plate, only tongue sensations could be used to determine whether a swallowable bolus had been formed. Then subjects ingested the food based on memory of the number of mastication strokes as usual. Although the number of mastication strokes until the swallowing threshold varies between individuals and oral health conditions (19), most of subjects in the present study showed an increased number of mastication strokes on day 7. As subjects got accustomed to the palatal coverage, they may have instinctively learned that they must increase the number of mastication strokes to form a bolus for easy swallowing as it used to be. This may have resulted in the recovery of the BFI by day 7 to the same level as that on day 0.

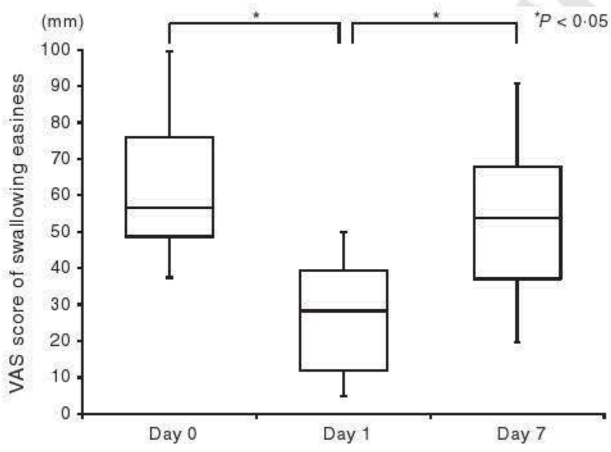

Fig. 5. Temporal changes in VAS score of swallowing easiness (*$P < 0{\cdot}05$). Vertical axis indicates how easy to swallow. The value of 0 mm represented 'the most difficult swallowing', and the value of 100 mm represented 'the easiest swallowing'. The VAS score was significantly lower on day 1 than on day 0 ($P < 0{\cdot}001$). The VAS score on day 7 significantly recovered to the original level of day 0 ($P < 0{\cdot}001$). There was no significant difference between days 0 and 7 ($P = 0{\cdot}131$). The box consists of first quartile, median and third quartile. Whiskers are minimum and maximum values.

In contrast, no significant changes in the value of ΔE were observed after wearing the palatal plate for 7 days. This indicates that masticatory performance was reduced by palatal coverage and it did not recover over time. It would be necessary to perform more than 60 strokes to recover the same value of ΔE as that exhibited without wearing the plate. That means it would be difficult to recover the reduction in masticatory performance due to palatal coverage by daily practice. Older people need greater number of mastication strokes and longer masticatory duration until the swallowing threshold than younger people (20). Furthermore, the number of mastication strokes increases in elderly individuals wearing complete dentures (21) and decreases with improvement in denture stability by implant attachments (16, 19). The present study supports these previous findings from the perspective of bolus formation, suggesting that subjects compensate for decreased masticatory performance by increasing the number of mastication strokes to form a easy swallowable bolus.

Indeed, the VAS score about swallowing easiness showed the same trend seen with the BFI, indicating a close positive relationship between the quality of bolus formation and swallowing easiness (13). In other words, bolus formation in the oral cavity by mastication positively affects comfortable swallowing in the pharynx. For instance, it is easy to imagine that a smaller number of mastication strokes would result in uncomfortable swallowing when a hard food is ingested (22). As subjects in the present study were young adults with a sufficient swallowing reserve capacity, even with a poor formed bolus, subjects would not show pharyngeal residue or aspiration and would instead only show reduced swallowing easiness. Actually, those who have good masticatory performance did not chew fewer times before swallowing than poor chewers, indicating that poor chewers swallow larger food particles according to their own swallowing threshold (23). In the present study, subjects did not increase the number of mastication when their masticatory performance reduced at day 1, because they were healthy young people and could swallow the larger particle bolus than usual according to their daily habit. Fontijn-Tekamp *et al.* (23) also suggested that other factors might be more important for swallow initiation than the particle size depending on masticatory performance, and the results of present study supported their concept. One of those factors to decide the swallowing threshold might be bolus formation and swallowing easiness in the pharynx; therefore, the subjects finally increased the number of mastication at day 7 to reach the swallowing threshold.

However, elderly individuals who need dentures may have reduced swallowing reserve by ageing, such as delayed swallowing reflexes, increased pharyngeal residue and increased laryngeal penetration (24, 25). Therefore, Poor bolus formation may lead to exacerbation of these functional reductions, resulting in increasing a risk of severe pharyngeal residue, aspiration and suffocation (20, 21). Therefore, after palatal coverage, elderly patients may require ingestion guidance including topics of bolus formation from the perspective of swallowing.

In general, about 1 week may be required to become accustomed to palatal coverage (6). In the present study, measurements were taken for 2 weeks as a preliminary experiment. After confirming that there were no major changes after 7 days of wearing the plate, the plate-wearing period was set to 7 days in line with previous studies. The adaptation period may have been longer for subjects in the older age group. In addition, although the palatal plates used in the present study were 1·5 mm thick and covered the entire palate, there are various different prosthetic designs depending on the individual and materials. Further consideration should be required, because the prosthetic design of palatal coverage is thought to affect masticatory and swallowing functions (5). In addition, further studies are needed to compare conditions in edentulous patients before and after denture delivery while considering bolus formation from the perspective of swallowing.

Conclusions

Although palatal coverage with an experimental palatal plate negatively affected bolus formation during mastication and swallowing, subjects adapted to feed with palatal coverage over time. As a result, bolus formation ability was recovered to the original level until 7 days as well as subjective evaluation about swallowing easiness. However, these adaptive changes were due to learning to increase the number of mastication strokes to compensate for the lowered masticatory performance for an easy swallowable bolus.

Acknowledgments

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Conflict of interest

No conflict of interest declared.

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