J Osaka Dent Univ 2015 (April) ; **49 (1)** : 1–10.

Ultrasonographic examination of how occlusal support is established by tongue movements during mastication

Masaki Kakudo[1], Norio Mukai[2], Junko Tanaka[2] and Masahiro Tanaka[2]

[1]Graduate School of Dentistry (Department of Fixed Prosthodontics and Occlusion), [2]Department of Fixed Prosthodontics and Occlusion, Osaka Dental University, 8-1 Kuzuhahanazono-cho, Hirakata-shi, Osaka 573-1121, Japan

We used ultrasonography to examine how insertion of a mandibular bilateral extension denture affected tongue movements during mastication. The study was done in two phases. Experiment I examined tongue movements during mastication of individuals with a well-established occlusal-supporting area. The subjects were 10 young individuals, 10 older dentate individuals and 10 individuals wearing complete dentures. Experiment II examined the effect of a mandibular bilateral extension denture on tongue movements during mastication. The subjects were 6 patients who were provided with mandibular bilateral extension dentures. Tongue movements during left and right unilateral mastication were examined by ultrasonography. Coronal B-mode images at the lowest points of five consecutive M-mode waveforms in each stage were traced. Height differences between the left and right sides of the tongue were compared between each stage.

In both left and right unilateral mastication, the height differences significantly decreased progressively between each stage in subjects with a well-established occlusal-supporting area. In all patients, no significant difference was observed between each stage before treatment. However, the height differences significantly decreased for each stage following treatment, and placement of the denture affected tongue movement in the final mastication stage. Placement of a mandibular bilateral extension denture affected tongue movement during mastication and the height differences of the two sides of the tongue gradually decreased as mastication progressed. (J Osaka Dent Univ 2015 ; 49(1) : 1–10)

Key words : Ultrasonography ; Tongue movements ; Coronal images ; Unilateral mastication ; Occlusal-supporting area

INTRODUCTION

Mastication is achieved through the action of multiple organs working together, including the teeth, periodontal tissue, masticatory muscles, temporomandibular joints, lips, cheeks, palate and tongue.[1] In particular, the tongue plays a major role in the preparation phase of mastication, which includes the transport of food to the occlusal surfaces of molars and transferring the food bolus to the pharynx once it has been chewed. Loss of teeth not only reduces masticatory efficiency, but also affects tongue form.[2] This indicates that the provision of suitable dentures for the edentulous portion of the alveolar ridge may affect bolus formation and transport by the tongue.[3] In other words, when the dentures are grinding food, it becomes a barrier between the oral vestibule and oral cavity proper, as well as the natural dentition and the residual ridge, followed by additional help from the tongue in bolus formation. It is believed that this movement is programmed automatic movement by central pattern generator. However, if a state of partial or complete edentulism is left without prosthetic treatment, tongue function will be impaired.

Observation of tongue movements during mastication has been studied using a variety of instruments. It has been suggested that these movements can be observed indirectly using a tongue pressure gauge

during mastication.[4] However, mounting the sensor in the oral cavity is inconvenient, as it disrupts the normal physiologic functioning of the oral environment. Videofluorographic examination of swallowing is possible for both morphological observation of structures and to determine the severity of pathology not only of the tongue, but also of the pharynx, and to visualize residual aspiration.[5] However, there can be serious problems, such as allergies caused by exposure to the contrast agent. Furthermore, special equipment is required, which is also costly.

Although it has been noted that monitoring of the soft tissue can be done with dynamic magnetic resonance imaging, time resolution is low at present. This diagnostic technique has not come into practical use in clinical settings as special equipment is required.[6] Conversely, ultrasonic examination is a simple procedure with no biological adverse effects, which maintains the normal physiological state of the oral environment and can record observations of tongue movement in real-time.[7, 8] Since the test food is not limited, the texture of food does not affect the examination.

Adapting to the dentures after placement often is a function of the subjective opinion of patient.[9] In addition, dentists usually carry out occlusal and denture adjustments following placement. However, there are limited opportunities to inspect mastication at the time of dental treatment. Although the effects of prosthetic treatment on the morphology and function of the tongue has been clarified, testing for movements of the tongue following insertion of dentures has not yet been performed.

In this study, we first examined tongue movements during mastication in subjects with a well-established occlusal-supporting area. Then we examined the differences in tongue movements during mastication before and after placement of dentures in mandibular bilateral distal extension cases. The null hypotheses of this study were : with masticatory progress, the height differences of the tongue during mastication do not change in young individuals, older people and those wearing complete dentures ; and the establishment of a satisfactory occlusal-supporting area with a mandibular bilateral extension denture does not affect tongue movements during mastication.

MATERIALS AND METHODS

This study was approved by the Osaka Dental University Ethics Committee (Approval No.110719).

Ultrasonography

These experiments used an ultrasonic device (SSA-250 A : Toshiba Medical Systems, Tochigi, Japan) and a microconvex-type electron probe (PVF-738 F : Toshiba Medical Systems) with a 56 mm × 15 mm contact area, 7.0 MHz center frequency and 80 mm depth for observing tongue movements. Acoustic coupler gel (Gelsonic L-250 : Nihon Kohden, Tokyo, Japan) was used during observations. While the patient was sitting on a dental chair with their head leaning back on the headrest, the Frankfort horizontal plane was set as parallel to the floor as possible (Fig. 1). The probe was secured under the chin using a custom-made fixing device (Fig. 2). It was confirmed that the subject could open and close without difficulty after mounting the probe.

Circular aluminum plates of 5 mm diameter and 0.2 mm thickness were attached with denture stabilizers (Touch Collect II, Shionogi & Co., Osaka, Japan) on the gingival aspect of the lingual side of the mandibular first molars, with the position of the probe determined using ultrasonography. The aluminum plates and stabilizers were removed after confirmation of the probe position. The tomographic site was set corresponding to the mandibular first molars. Next, the center of the tongue was confirmed to be identical with the M-mode cursors, which were in the center of the

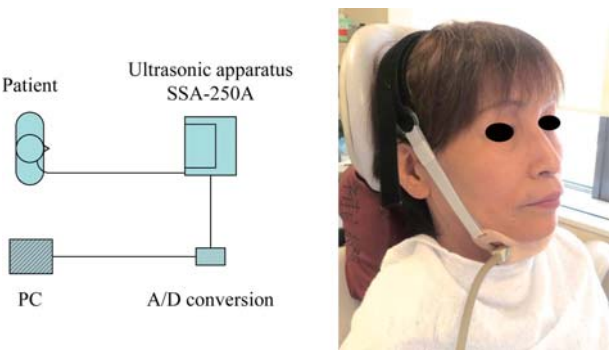

Fig. 1 Use of the device for recording tongue movements.

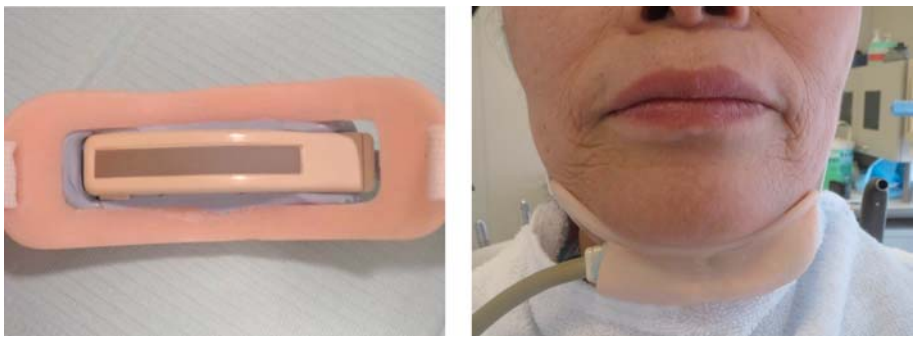

Fig. 2 Custom chin device with micro convex electron probe (PVF-738F).

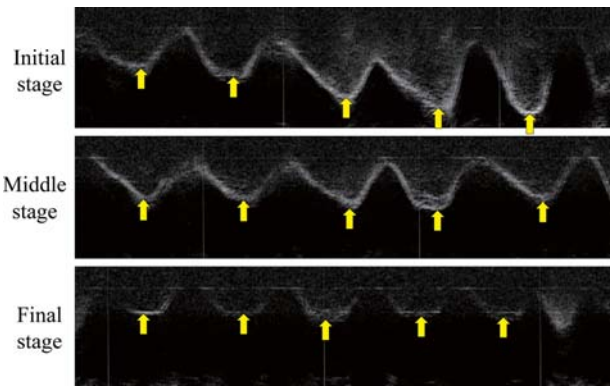

Fig. 3 Example of the classification of M-mode images. Arrows indicate when the B-mode images were recorded.

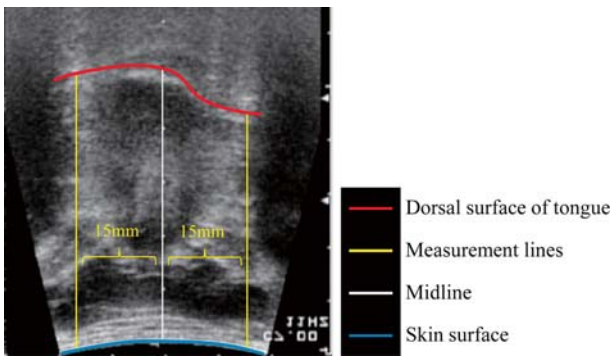

Fig. 4 Height of the left and right sides of the tongue in the B-mode image.

screen in the ultrasound images. Examination and correction of the probe position was performed as necessary for each measurement.

Experiment I

Examination of tongue movements during mastication in subjects with a well-established occlusal-support area.

Subjects

The subjects were 10 young dentate subjects (seven men and three women 27 ± 2 years of age), 10 older dentate subjects (three men and seven women, 72 ± 7 years of age) and 10 individuals (two men and eight women, 72 ± 8 years of age) wearing complete dentures, with which they were satisfied.

Test food and exercises

Test exercises comprised both left and right unilateral mastication. Subjects were instructed to swallow at their normal timing. If multiple swallows were observed, tongue movements during mastication until the time that the first swallow was observed were used as the observation target. The test food was 10.0 g of cooked rice.

Observation of tongue movements using ultrasonography

The recording mode for ultrasonography was set to M + B-mode, which could simultaneously measure M-mode (motion-mode : an animated image observed in a time-series site) and B-mode (brightness-mode : a two-dimensional image displayed by repeated transmission received as an ultrasound beam). This display method is based on ultrasonic di-

Table 1 Height differences during mastication in each subject

Subject	Group	Height difference in left mastication			Height difference in right mastication		
		Initial stage	Middle stage	Final stage	nitia stage	Middle stage	Final stage
A	Young	8.846	3.88	1.992	–7.59	–3.126	–2.332
B	Young	4.666	2.296	1.168	–7.78	–4.442	–3.764
C	Young	8.384	2.638	–0.644	–17.224	–5.994	–2.34
D	Young	1.998	0.628	–0.458	–10.774	–5.276	–2.794
E	Young	5.436	3.748	2.878	–8.074	–4.866	–0.086
F	Young	7.56	7.266	0.67	–9.982	–8.976	–3.22
G	Young	8.626	2.592	0.48	–8.648	–0.648	1.256
H	Young	5.952	3.38	1.74	–9.856	–4.81	–3.658
I	Young	9.26	9.246	3.192	–14.104	–8.124	–0.058
J	Young	10.25	5.216	1.944	–10.888	–6.214	–3.56
K	Older	4.238	3.632	1.507	–5.038	–5.135	–2.931
L	Older	10.29	7.594	2.448	–8.478	–5.419	–1.272
M	Older	11.032	7.139	1.682	–10.141	–5.604	–1.244
N	Older	9.33	5.372	1.08	–8.628	–5.358	0.09
O	Older	13.288	5.612	–0.722	–6.528	–2.304	0.356
P	Older	13.254	7.278	4.42	–4.082	–0.916	–0.958
Q	Older	7.922	4.77	1.884	–8.264	–5.024	0.248
R	Older	11.06	8.586	6.006	–6.21	–0.452	1.418
S	Older	6.804	4.25	3.396	–5.72	–1.604	–0.794
T	Older	8.114	6.92	3.246	–7.816	–3.6	0.784
U	Denture	4.442	2.842	1.622	–2.212	–0.962	0.418
V	Denture	6.364	2.114	1.608	–8.066	–4.894	–2.606
W	Denture	9.104	6.822	1.048	–5.462	–3.906	1.692
X	Denture	6.156	4.26	1.761	–5.984	–0.714	–0.168
Y	Denture	9.134	7.054	2.182	–11.438	–2.48	0.278
Z	Denture	11.114	7.716	2.816	–6.594	–6.876	–0.222
AA	Denture	15.268	10.33	4.84	–10.09	–6.338	0.648
AB	Denture	13.526	6.796	3.948	–11.27	–3.034	0.932
AC	Denture	15.872	12.12	4.064	–12.172	–3.008	–0.942
AD	Denture	9.59	6.024	3.24	–10.562	–7.866	–4.074

(mm)

agnosis. The series of extracted images were converted from analog to digital and stored in a personal computer. Waveforms of the tongue movements in M-mode images were classified into the following three stages ; initial (chewing immediately after start of the experiment), middle (period between the initial and final stages), and final (just before swallowing) (Fig. 3).

Coronal B-mode images were extracted and traced on tracing paper (Ortho/Trace : Rocky Mountain Orthodontics, Denver, CO, USA) at the lowest points in five consecutive M-mode waveforms for each stage (Fig. 4). Height differences calculated by subtracting the height (from the lower chin skin surface to the dorsal surface of the tongue) of the left side from the right side 15 mm from the midline of the tongue were compared at each stage. Digital calipers (CD67-S20PM : Mitutoyo, Kanagawa, Japan) were used for measurement of the distance on the tracing paper. The average values of the height differences in the five consecutive B-mode images of each stage were compared for each group.

Statistical analysis

Statistical analysis software (SPSS ver.19 : IBM Japan, Tokyo, Japan) was used for repeated one-way

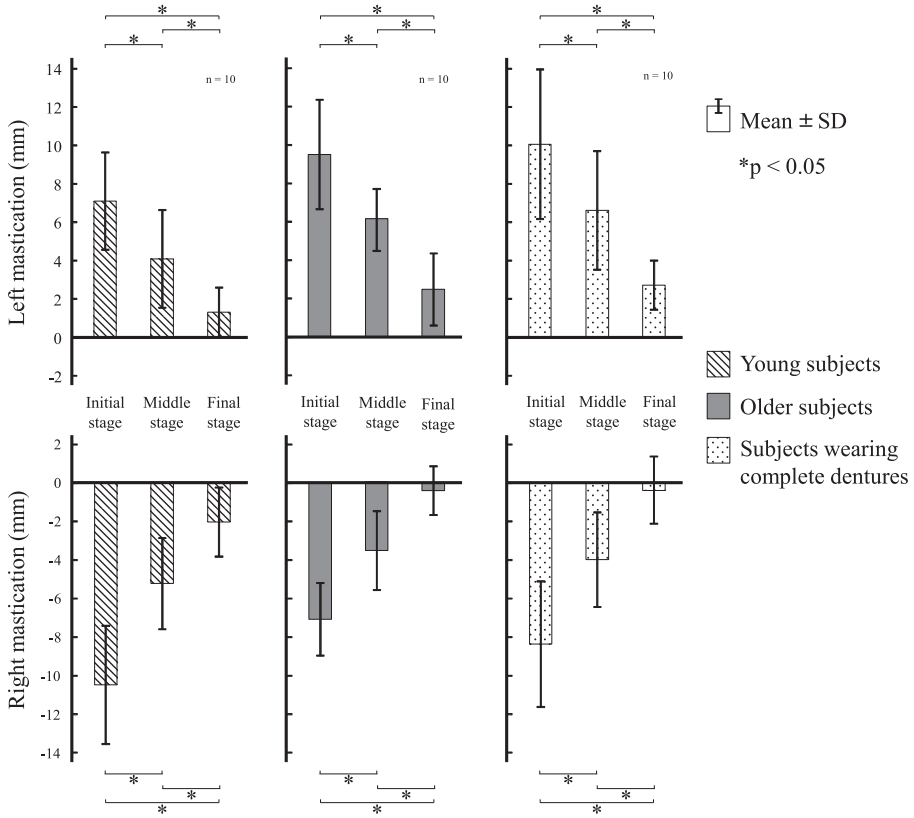

Fig. 5 Height differences during mastication in each subject.

analysis of variance (ANOVA), for which the analyzed factor was the selected stage. If a statistically significant difference was observed in the ANOVA, Tukey's test was carried out as a multiple comparison test. The significance level was set at 5%.

Experiment II

Examination of the effect of insertion of a mandibular bilateral extension denture on tongue movements during mastication.

Subjects

Six patients (one man and five women 71 ± 4 years of age), who needed mandibular bilateral extension dentures, were selected. One person had Eichner classification B2, three had class B3 and two had class B4. The first and second molars of all patients had been lost. All of them received a mandibular bilateral extension denture fabricated according to traditional methods at Osaka Dental University Hospital. At an appropriate time after placement of the denture, we confirmed that each patient was accustomed to chewing without pain.

Observation of tongue movements by ultrasonography

Observations were carried out before and after placement of the mandibular bilateral extension denture. Ultrasonography was done the same as in Experiment I. The first observation was done at the time of the final impression for fabrication of the denture. The second observation was done at a recall at least 6 months after placement of the denture.

Statistical analysis

Statistical analysis software (SPSS ver.19 : IBM Japan, Tokyo, Japan) was used for repeated two-way ANOVA, for which the analyzed factors were the selected stage and the presence of the denture. If a statistically significant difference was observed in the

ANOVA, Tukey's test was carried out as a multiple comparison test with a significance level of 5%. If there is a significant difference in the interaction, simple main effects test was carried out.

Table 2 Height differences during mastication before and after treatment in patients

Patients	Dentures	Height difference in left mastication			Height difference in right mastication		
		Initial stage	Middle stage	Final stage	Initial stage	Middle stage	Final stage
A	−	11.030	5.686	8.358	−10.652	−8.368	−8.426
B	−	9.078	5.138	5.312	−6.278	−3.596	−8.920
C	−	8.738	8.526	7.158	−8.158	−5.534	−5.762
D	−	4.174	4.996	6.284	−11.432	−4.812	−5.786
E	−	9.099	7.599	5.115	−9.188	−6.447	−7.667
F	−	10.770	6.608	6.009	−7.244	−8.882	−5.077
A	+	8.996	6.536	2.470	−10.900	−2.344	−0.412
B	+	7.164	5.576	5.108	−9.200	−1.972	0.404
C	+	7.830	4.122	−0.492	−6.814	−4.960	−2.326
D	+	7.208	7.006	1.766	−8.164	−5.324	−2.322
E	+	8.084	1.998	2.276	−8.795	−4.787	−1.009
F	+	8.499	5.233	1.897	−7.779	−6.892	−3.033

(mm)

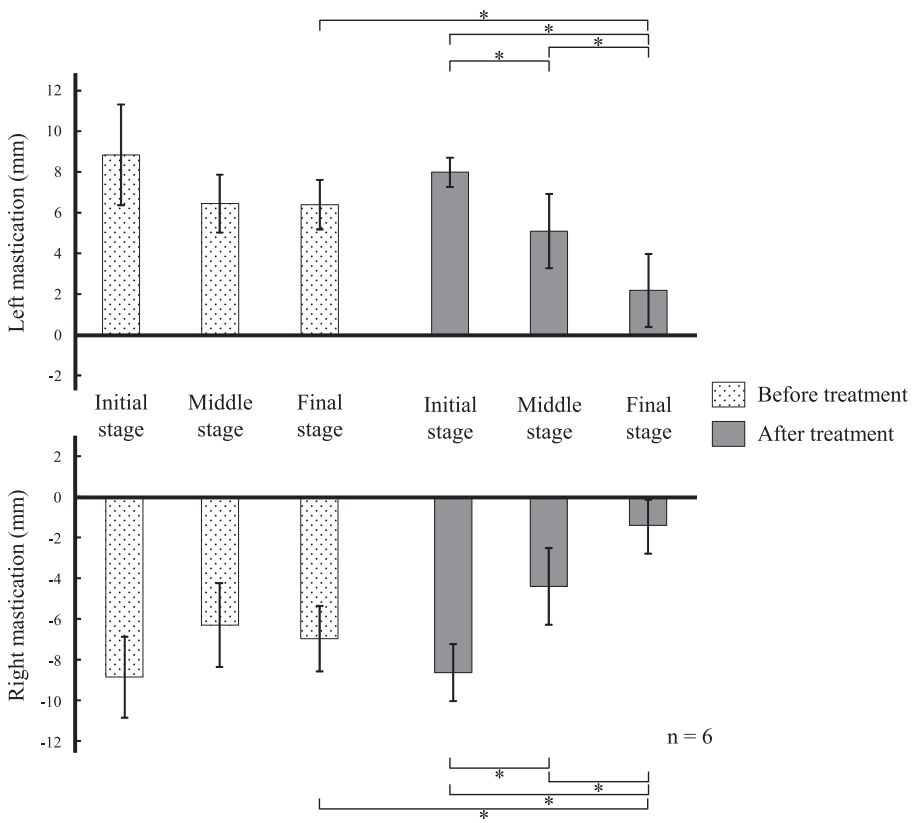

Fig. 6 Height differences during mastication.

RESULTS

Experiment I

Table 1 shows changes in the differences in height between the left and right side of the tongue in each subject. With both left and right unilateral mastication, the height differences significantly decreased progressively between each stage in the subjects with a well-established occlusal-support area ($p<0.05$) (Fig. 5).

Experiment II

Table 2 shows changes in the difference in height between the left and right sides of the patients' tongues. In all patients, no significant difference was observed between each stage before treatment ($p>0.05$). However, the height difference significantly decreased progressively between each stage after treatment ($p<0.05$), and approached that of subjects with a well-established occlusal-support area. According to statistical analysis, wearing dentures affected tongue movements in the final mastication stage ($p<0.05$) (Fig. 6).

DISCUSSION

The tongue is composed of muscle tissue, and it has been suggested that it is affected by age-related changes.[10, 11] In addition, it has been reported that the state of the occlusal-support area may affect tongue movements.[12] In this study, which is the first to observe tongue movements during mastication of dentate subjects with well-established occlusal-support, we examined the differences between older and young individuals. In the edentulous older individuals with complete dentures, we studied the tongue movements during mastication when occlusal support was maintained only by the dentures. To analyze the effect of the denture on tongue movements during mastication, we investigated the movements during mastication before and after placement of the mandibular bilateral extension denture.

Measurement methods

To measure the movement of the tongue during mastication in Experiment I, it was necessary to achieve uniformity of the occlusal-support areas in the subjects. All subjects in Experiment I were Eichner class A1. However, as masticatory efficiency was significantly lower with dentures compared to natural dentition,[13–15] and as dentures seemed to affect tongue movements during mastication, subjects with complete dentures were included as the target of Experiment I. Initially, in the dentate group, the tongue had a significant twisting motion towards the direction of the chewing side, which was necessary to carry the food on the dorsum of the tongue to the occlusal surfaces of the mandibular molars during mastication.[16, 17] In Experiment II, to examine the effect of the loss of the residual ridge and teeth in the mandibular molar region on tongue movements during mastication, we selected subjects with Eichner class B, who had lost the occlusal support of the mandibular first and second molars and who had mandibular bilateral extension dentures.

Since the size and characteristics of the food affect the masticatory function test, we decided to use test food that would be suitable for the purpose of this study.[18] In order to observe the dynamics of tongue movement during mastication, the test food should be similar to food commonly consumed in daily life, have an even composition throughout, and have a size and weight that is easily defined. In addition, it is desirable to have food that is not irritating to the sensory receptors in taste or smell. Therefore, we selected cooked rice, the staple food of the Japanese, as the test food, because it is easily ingested and palatable, and reproduces oral function close to that observed in the subjects' normal daily life.[19] Rice at 20 g and 15 g quantities was deemed excessive, as chewing this amount at one time had an exaggerated effect on tongue movements owing to the bolus size. Therefore, we selected 10 g, which was the maximum amount that did not noticeably affect tongue movement.[20]

It has been reported that external fixation of the probe by attaching the device or by hand manipulation by the operator is unnecessary with the use of a microconvex probe when ultrasound is used for observation of the dynamics of tongue movement in the sagittal plane during mastication.[21] However, if the

probe is fixed by a finger, the speed and direction of movement of the tongue and the probe is the same, and movement of the probe may be mistaken for movement of the tongue.[22] In this study, we designed a probe-fixing device attached to the subject's head to ensure that the probe used for measurements was correctly placed.

In addition, to insure that the subjects' tongue movements during mastication were as close as possible to those elicited during their normal routine, the subjects were not given a particular time-frame to finish mastication. The determination of swallowing was carried out by confirmation of the trajectory of the bolus, which was determined by observing the pressing of the dorsal surface of the tongue to the palate during swallowing on the M-mode waveform.[20–23] By setting the cursor displayed on the B-mode screen at a desired position, the M-mode may be displayed at different time intervals as sequential images at a particular site.

In this study, the cursor position on the B-mode screen was set to the median dorsal surface of the tongue to track the superoinferior movements of the tongue during mastication. This was done in order to observe an image equivalent to the M-mode ultrasound image of tongue movement dynamics that Nakanishi *et al.* had reported.[24] Mastication of the food began at the initial stage, where the M-mode waveform showed a relatively large cycle and amplitude. After the middle stage was reached, the cycle and amplitude of the M-mode waveform stabilized and rhythmical motion trajectories of the tongue were recorded.[20] This suggested that bolus formation was being performed by chewing the food and mixing it with saliva.

In the final stage, the cycle and amplitude of the M-mode waveform became smaller and the motion trajectory of the tongue remained closer to the palate. By observing these changes, it became possible to correctly classify the M-mode waveform for the three stages. In addition, because of differences in size of the oral cavity and the tongue, height differences between the right and left sides were calculated in this study as an indicator of motion of the tongue during mastication.

Results of Experiment I

In all groups, the height differences of the tongue during left and right side mastication became smaller when progressing through the three stages. The initial stage showed the largest height difference between the two sides in any group. This seems to suggest that a great torsional scooping movement occurred as the tongue transported the food to the occlusal surface of the chewing side to crush it.[22] The height difference between the left and right sides of the tongue in the middle stage showed a value less than at the initial stage in all groups. Since the adhesion of the cooked rice was reduced by incorporation of saliva during mastication, the bolus flow into the pharynx (stage II transport) occurred even during chewing.[25] Since it is believed that the amount of bolus chewing in the middle stage is reduced, leading to a smaller height difference as compared with the initial stage, tongue movements are also reduced.

To move toward swallowing immediately after mastication ends, the intraoral pressure is enhanced as the entire tongue pushes the bolus of food to the palate,[4] reducing the height difference between the left and right sides of the tongue to the smallest value during the final stage. In other words, the final stages occurred as the tongue was pressed against the hard palate in dentate individuals, and against the palatal plate of those with maxillary complete dentures. Based on the above information the first null hypothesis was dismissed.

Results of Experiment II

As with the dentate subjects in Experiment I, the height differences between the left and right sides of the tongue in patients in Experiment II showed the largest value during the initial stage before placement of the denture. However, no significant difference was observed between each stage. It seems that loss of the occlusal-support area of the posterior teeth caused compensatory movements by the tongue in order to keep the food in the oral cavity proper from the start to the end of mastication.[3] Torsional movement necessary for scooping up the food that had fallen to the floor of the mouth[22] continued even during the final stage, causing the height difference of the tongue to

show no decrease with either left or right side mastication.

However, height differences of the tongue after placement of a mandibular bilateral extension denture were significantly reduced, similar to the situation with dentate subjects in Experiment I. This suggests that as mastication progresses, the recovery of the posterior occlusal-support area that occurs by placement of a denture affects tongue movements during mastication. When a denture with mandibular distal extensions is placed, we observed adaptation to normal chewing conditions in 6 months.[26] We noted in the present study that the patients were able to masticate adequately using the denture when we observed the tongue movements at the recall appointment which was at least 6 months after placement of the denture.

We concluded that both the oral vestibule and the oral cavity proper were able to establish normal physiology when a mandibular bilateral extension denture was placed. Because this eliminated the need for compensatory movements by the tongue, tongue function during mastication was similar between dentate individuals and those with complete dentures. Thus we were able to dismiss the second null hypothesis.

CONCLUSION

When we observed mastication in environments with well-established occlusal support, we found that tongue movement gradually decreased with the progress of mastication.

We would like to thank the members of the Department of Fixed Prosthodontics and Occlusion, Osaka Dental University. This study was supported in part by Osaka Dental University Research Funds (No.14–06).

REFERENCES

1. Yamada Y. Swallowing. In : Morimoto T, Ninomiya Y, Iwata K, eds. Basic physiology for dental students. Tokyo : Ishiyaku Publishers, 2014 : 355–369.
2. Kaku S. Comparison of morphology of the tongue space between dentulous and edentulous jaws. *J Kyushu Dental Society* 1987 ; **41** : 481–493. (Japanese)
3. Kohno S. Occlusal form and masticatory function of molars. *Meirin JDEOH* 2009 ; **12** : 3–8. (Japanese)
4. Naito Y, Narita T, Shioda Y, Kondo Y, Fukumoto M, Takeuchi T, Yugi S, Gionhaku N. Comparison of tongue pressure during mastication between young and elderly dentate subjects. *Jpn J Gerodontology* 2011 ; **26** : 69–77. (Japanese)
5. Tanimoto K. Diagnostic and testing (evaluation). In : Kariyasu M, Shimizu M, Tsuda G, Honda T, eds. Clinical dysphagia : Actual and concept of rehabilitation. Tokyo : Ishiyaku Publishers, 2008 : 132–154.
6. Honda Y. Kinetic MRI using high-speed sequence to evaluate swallowing －Comparison with videofluorography－. *Oral Radiology* 2003 ; **19** : 14–21.
7. Nakanishi N, Ishida Y, Tanioka T, Nakayama F, Tanaka M, Kawazoe T. Influence of experimental loss of occlusal support on tongue movement during swallowing. *J Osaka Dent Univ* 2007 ; **41** : 169–172.
8. Blissett A, Prinz JF, Wulfert F, Taylor AJ, Hort J. Effect of bolus size on chewing, swallowing, oral soft tissue and tongue movement. *J Oral Rehabilitation* 2007 ; **34** : 572–582.
9. Hashimoto M, Shiga H, Kobayashi Y. Masticatory performance and masseter muscular activities before and after complete denture treatment. *J Jpn Society Stomatognathic Function* 2012 ; **19** : 10–18. (Japanese)
10. Tamine K, Ono T, Hori J, Hamanaka S, Maeda Y. Age-related changes in tongue pressure during swallowing. *J Dental Research* 2010 ; **89** : 1097–1101.
11. Fei T, Polacco RC, Hori SE, Molfenter SM, Peladeau-Pigeon M, Tsang C, Steele CM. Age-related differences in tongue-palate pressures for strength and swallowing tasks. *Dysphagia* 2013 ; **28** : 575–581.
12. Nakanishi N, Miki H, Tanaka M, Kashiwagi K, Imai A, Kawazoe T. An ultrasound examination of oral transit. *J Jpn Society Stomatognathic Function* 2002 ; **9** : 37–43. (Japanese)
13. Riberio JAM, Resende CMBM, Lopes ALC, Junior WM, Roncalli AGR, Farias-Neto A, Carreiro AFP. Evaluation of complete denture quality and masticatory efficiency in denture wearers. *Int J Prosthodontics* 2012 ; **25** : 625–630.
14. Goiato MC, Garcia AR, Santos DM, Zuim PRJ. Analysis of masticatory cycle efficiency in complete denture wearers. *J Prosthodontics* 2010 ; **19** : 10–13.
15. Koshino H. Tongue motor skill evaluated by ultrasound system and masticatory performance evaluated by sieving method. *J Jpn Prosthodontics Society* 1994 ; **38** : 799–810. (Japanese)
16. Tomura Y. Studies on the morphological changes of the tongue movements during mastication by X-ray TV cinematography 2. The observations from the frontal direction. *J Tokyo Dental College Society* 1980 ; **80** : 33–51. (Japanese)
17. Abd-El-Malek S. The part played by the tongue in mastication and deglutition. *J Anatomy* 1955 ; **89** : 250–254.
18. Ahlgren J, Öwall B. Muscular activity and chewing force : a polygraphic study of human mandibular movements. *Archives of Oral Biology* 1970 ; **15** : 271–280.
19. Imai A, Kawazoe T, Tanaka M, Iwayama Y, Furuichi E. Fundamental studies on the propriety of steamed rice as a test food for the evaluation of the masticatory function. *J Jpn Prosthodontics Society* 1997 ; **41** : 856–861. (Japanese)
20. Imai A. A study on the mastication of steamed rice for evaluation of masticatory function. *J Jpn Prosthodontics Society* 1988 ; **42** : 147–156. (Japanese)
21. Imai A, Kawazoe T, Tanaka M, Miyamoto M, Tatsuta M, Seki R. Observation of tongue movement during mastication of various food using ultasonography. *J Jpn Prosthodontics Society* 1966 ; **40** : 338–346. (Japanese)
22. Peng CL, Jost-Brinkmann PG, Miethke RR, Lin CT. Ultrasonographic measurement of tongue movement during swallowing. *J Ultrasound Medicine* 2000 ; **19** : 15–20.

23. Imai A, Tsuji I, Kimura K, Tatsuta M, Tanaka M, Kawazoe T. Study on movements of tongue and mandible in progress to masticate foods. *J Jpn Society Stomatognathic Function* 1997 ; **4** : 43–50. (Japanese)
24. Nakanishi N, Imai A, Kojima R, Kashiwagi K, Tanaka M, Kawazoe T. Tongue movement during swallowing following mastication. *J Jpn Society Stomatognathic Function* 2002 ; **8** : 129 –130.
25. Palmer JB, Rudin NJ, Lara BAG, Crompton AW. Coordination of mastication and swallowing. *Dysphagia* 1992 ; **7** : 187–200.
26. Kakudo M, Mukai N, Tanaka J, Tanaka M. A case of diachronic observation on tongue movement before and after the removable partial denture treatment using ultrasonography. *J Jpn Prosthodontics Society* (in press). (Japanese)