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CLINICAL RESEARCH

Morphological magnetic resonance imaging study of oral submucosal tissue and buccinator muscle dynamics in the posterior dentition: A clinical study

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ABSTRACT

Statement of problem. The relationship between the buccal mucosa-tongue side wall contact points and at what ratio the submucosal tissue (ST) and buccinator muscle (BUC) change during function are unclear.

Purpose. The purpose of this clinical study was to clarify the space and dynamics of the ST and BUC in complete denture wearers by using magnetic resonance imaging and to investigate how denture base shape affects space sealing and the relationship between the ST and BUC.

Material and methods. Eight edentulous participants wearing maxillary and mandibular complete dentures were enrolled. Wax was added to the buccal border of the dentures, and axial and coronal magnetic resonance imaging scans were made during mandibular rest (MR) to observe the relationship of the buccal mucosa and tongue above the retromolar pads. In addition, on axial images, the thicknesses of the ST and BUC were measured at 3 sites: second molar center, second molar distal (SMD), and retromolar pad center (RPC). Coronal images were made during MR, partial mouth opening, and midmouth opening (MMo). At second molar center, SMD, and RPC, the thicknesses of the ST and BUC were measured at the maxillary buccinator attachment region (point A), the mandibular buccinator attachment region (point B), and the median point between A and B (point M).

Results. During MR, contact sealing of the buccal mucosa and tongue on the RPC was noted in 81% of participants. After expanding the denture base with wax, contact was lost in 86% of participants. The ST and BUC thicknesses on the RPC decreased significantly with the addition of wax. During MR, the ST became significantly thicker the further posteriorly it was located. The ST was significantly thicker at point M than at point A for all sections, regardless of mouth opening. The ST and BUC thicknesses in SMD and RPC were significantly thicker at point M than at point B during MR and MMo. The differences of the ST and BUC thicknesses depending on the opening amount were observed only at the point M. In the RPC, the thickness of the ST and BUC decreased significantly as the opening amount increased (ST thickness between MR and partial mouth opening, MR, and MMo: P=.007, P=.001, BUC: P=.018, P=.001, respectively)

Conclusions. The thickness of the ST and BUC differed depending on the site. During mouth opening, these changes in thickness at each site are proportional to the differences in ST and BUC thickness. (J Prosthet Dent 2020;■:■-■)

Food sediment rarely remains behind the maxillary and mandibular second molars after meals in healthy dentate individuals.[1] As the tongue is pressed against the dentition during mastication and swallowing, the buccal mucosa and tongue fill and seal off the space behind most posterior teeth. When the mandibular distal extension is left untreated over a prolonged period, the tongue, as well as the buccal and sublingual submucosal tissues (STs), changes shape to fill the defect space, thereby completely sealing the posterior portion.[2]

This sealing function in the distal extension is also important during prosthetic treatment for the edentulous jaw. Observation of mandibular complete dentures fitted to the alveolar ridge shows that most of the retromolar pad is covered by the denture base, suggesting close conformity of

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Clinical Implications

As the denture border can be sealed by contact between the denture border and oral mucosal tissue, understanding the dynamics of functioning muscles and oral submucosal tissue is important in sealing the denture base circumference and preventing mandibular complete denture dislodgement.

the intaglio surface of the denture in the retromolar pad area with the mucosa and contact between the buccal mucosa and tongue on the denture polished surface covering the retromolar pad during mandibular rest (MR).[3] The contact point is referred to as the buccal mucosa-tongue side wall contact (BTC) point,[4] and because the formation of this BTC point is important for mastication and swallowing, the prosthetic treatment should not interfere. What kind of relationship this BTC point maintains with the buccal ST and buccinator muscle (BUC) and at what ratio the ST and BUC change during functioning remain unanswered.

As muscles are the main factors in managing the seal of the denture border, fabricating dentures that extend to the movable muscle attachments are a standard practice.[5-7] However, extending to the area of the muscle attachment often does not result in sufficient retention and stability. The factors contributing to denture stability are the relationship of the denture base to the underlying tissues, the external surface and border to the surrounding orofacial musculature and the opposing occlusal surfaces.[8] Understanding the dynamics of functioning muscles and oral ST is important in implementing the sealing of the denture base circumference to solve the problem of mandibular complete denture dislodgement.

Studies related to these topics have reported on the role of the muscle pressure of the buccal mucosa surface layer in morphological changes during mastication or mouth opening and closing[9,10] and on soft tissue during impression making.[11,12] However, studies that investigated the underlying morphology or measured the dynamics of the buccal ST and BUC are lacking. The purpose of the present investigation was to clarify the state of space sealing around the retromolar pad by using magnetic resonance imaging (MRI) to examine the dynamics of the ST and BUC during MR and mouth opening in complete denture wearers. This research also investigated how the denture border from the retromolar pad to the buccal shelf affected space sealing and the dynamics of the ST and BUC. The null hypothesis was that the thickness of the oral ST and BUC would not change when wax was added to the buccal border of the mandibular denture and when mouth opening.

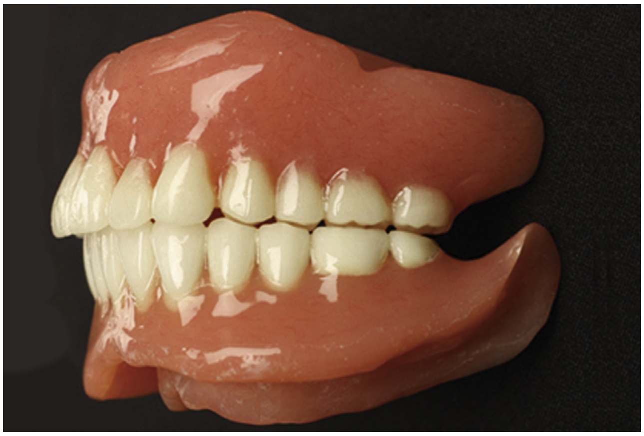

Figure 1. Removable complete dentures. Denture base margin at posterior border of mandible set at exterior margin of buccal side of retromolar pad and base margin shaped so that buccal mucosa did not cover or obstruct retromolar pad. Space of at least 3 mm between maxillary tuberosity and retromolar pad to secure sufficient occlusal height.

MATERIAL AND METHODS

This descriptive clinical study was approved by the Ethics Committee of the Tohoku University Graduate School of Dentistry (Approval number: 20-24). Participants were provided explanations in advance regarding the significance and contents of this research, and written informed consent was obtained, including consent to participate and to publish the findings. The inclusion criteria were participants wearing maxillary and mandibular complete dentures. Individuals with temporomandibular disorders, dental implants, or magnetic attachments were excluded.

Based on a pilot study and assuming a large effect size, a sample size of about 8 was needed to achieve 0.8 power to detect a significant difference. Five men (mean age: 77.2 years, range: 68-86 years, mean length of service of prostheses: 11.4 years) and 3 women (mean age: 66.3, range: 56-72, mean length of service of prostheses: 7.4) were enrolled. Six participants were completely edentulous, 1 woman had an edentulous maxilla and a mandibular overdenture, and 1 man had maxillary and mandibular overdentures.

Dentures were fabricated by 3 dentists, including an author (J.A.), with sufficient knowledge of the mandibular complete denture attachment mechanism.[3] These dentures were characterized by a mandibular posterior denture border being set on the buccal outer edge of the retromolar pad, the border being shaped so as not to prevent the buccal mucosa from covering the retromolar pad, and a space of at least 3 mm between the maxillary tuberosity and the retromolar pad to achieve sufficient occlusal height (Fig. 1).

MRIs were made using a 1.5-T scanner (Achieva Nova Dual; Koninklijke Philips N.V.). Surface coils

Figure 2. Dentures with utility wax added.

(SENSE Flex-M; Philips N.V.) were fixed on the left and right sides, and imaging was performed with participants in the dorsal position. T2-weighted images were acquired with the turbo spin echo method[13] with the following parameters: repetition time = 3000 millisecond; echo time = 100 millisecond; flip angle = 90 degree; slice width = 5 mm; field of view = 250 mm; and imaging time = 78 second.

During imaging, the surface joining the center of the spinal cord and the center of the mandible were kept parallel with the sagittal reference plane. In addition, the head was positioned so that the horizontal reference plane was perpendicular to a line joining the second and fourth cervical vertebrae. To prevent complete denture dislodgement during MRIs, a small amount of denture adhesive (Mizugrip; Kobayashi Pharmaceutical Co, Ltd) was applied to the intaglio surface.

The test dentures were affixed to the maxillary and mandibular jaws, and axial and coronal images were acquired at the MR position. Coronal images were made in the order starting from MR to partial mouth opening (PMo) to midmouth opening (MMo). The standardization of the mouth opening was that the amount of MR was 2 mm, PMo was 15 mm, and MMo was 30 mm. Before the experiment, the participants practiced mouth opening while the opening amount was measured. Utility wax (GC Dental) was added only to the left side of the buccal denture border from the mesial edge of the first molar to the level of half the height of the retromolar pad; the condition was described as WAX (+) (Fig. 2). After the practitioner had molded the border in the same way as a denture impression, axial and coronal images were acquired during MR.

MRIs recorded in Digital Imaging and Communications in Medicine format were expanded 3-fold with design software (Illustrator CS5; Adobe Systems Inc), and the 3 sites of the oral mucosa region, the border between the oral ST and BUCs, and the buccal margin of the BUCs were traced on a personal computer screen.

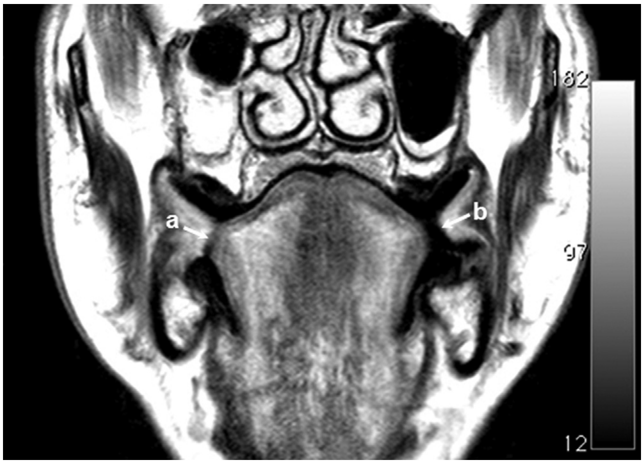

Figure 3. BTC point formation during WAX (-) and (+) on coronal image. (a) BTC point formed during WAX (-), (b) BTC point disrupted during WAX (+). BTC, buccal mucosa-tongue side wall contact.

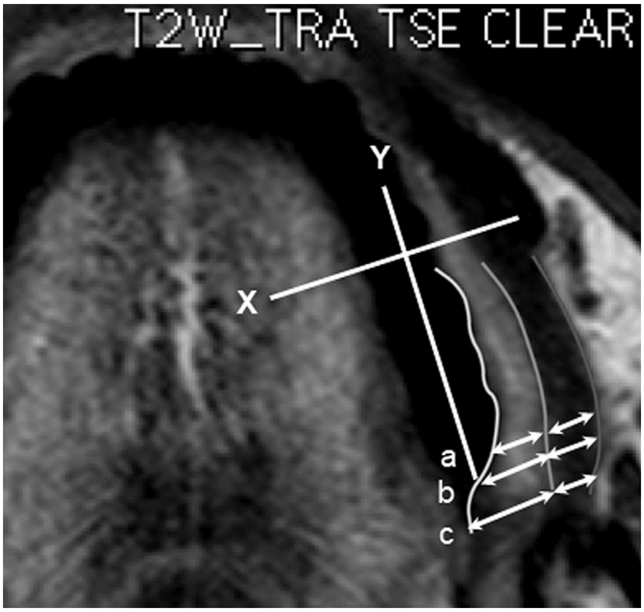

Figure 4. Measurement of ST and BUC thickness on axial images. Three sites of (a) second molar center from anterior part, (b) second molar distal end, and (c) retromolar pad center set as measurement sites, and thickness of oral ST and BUC parallel to X axis during WAX(–) and WAX(+) was measured. BUC, buccinator muscle; ST, submucosal tissue.

The thickness at each site was measured by using a line tool.

The BTC on the retromolar pad could be observed on the coronal images. To determine the presence of the BTC point in the retromolar pad denture base during MR, the BTC point was considered to have formed (+) if the space between the buccal mucosa and tongue was ≤1.0 mm on coronal images and not to have formed (–) for any spaces larger than this (Fig. 3).

In the axial image, a straight line joining the mandibular second premolar and the mandibular first

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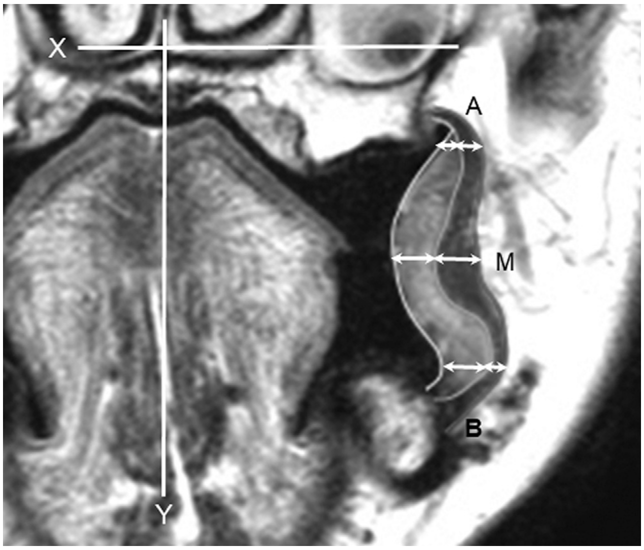

Figure 5. Measurement of ST and BUC thickness on coronal images. Measurement sites 5 mm below area where buccinator medial margin came into contact with maxillary bone (point A), 5 mm above where buccinator medial margin came into contact with mandibular bone (point B), and central point between points A and B (point M). BUC, buccinator muscle; ST, submucosal tissue.

and second molars was set as the Y axis in a rectangular coordinate system, and an intersecting line was set as the X axis. The 3 sites of the second molar center (SMC), the second molar distal (SMD) end, and the retromolar pad center (RPC) were set as the measurement sites. The thickness of the oral ST and BUCs parallel to the X axis during WAX (-) and (+) was measured (Fig. 4). The ratios of the ST and BUC thickness (ST/BUC ratio) on axial images were also calculated.

In the coronal image, a line passing through the center was set as the Y axis, and a line intersecting the Y axis was set as the X axis. The left side oral ST and BUC thickness parallel to the X axis were measured. The measurement points were point A (5 mm below the area where the BUC medial margin contacted the maxillary bone), point B (5 mm above where the BUC medial margin contacted the mandibular bone), and point M (the central point between points A and B). The measured coronal sections were the 3 sites of SMC, SMD, and RPC (Fig. 5).

A statistical software program (SPSS Statistics for Windows, v17.0; SPSS, Inc) was used for statistical analysis with a 2-way repeated measure analysis of variance and the Tukey honest significant difference test. When the interaction was significant, the Bonferroni simple main effects test was performed (α=.05).

RESULTS

Table 1 shows the results for the BTC point formation during WAX (-) and (+) during MR. Six participants showed the BTC point formation on the left and right sides. In 1 participant, no BTC point was formed only on the right side, and, in 1 participant, no point was formed on either side. In 1 participant, the wax addition had no effect, and the BTC point was not lost. The wax addition prevented BTC point formation at a probability of approximately 86%. Moreover, the 1 participant in whom a BTC point did not form on either side during WAX (-) was excluded from analysis.

Table 2 shows the results of the 2-way repeated measures ANOVA on ST and BUC thicknesses and the ST/BUC ratio on the axial images during MR. The ST thickness during WAX (-) increased significantly at the more posterior sites. Meanwhile, no significant difference was found in BUC thickness. During WAX (+), the thickness of SMC increased by approximately 20% as compared with that during WAX (-). Conversely, the thickness decreased by approximately 25% in SMD, whereas the thickness of the ST in RPC decreased by >50% as compared with before the wax addition. During

Table 1. BTC point formation during mandibular rest with and without wax on coronal images

	Right Side	Left Side	
Participant	**WAX (-)**	**WAX (-)**	**WAX (+)**
1	+	+	-
2	+	+	-
3	-	-	-
4	+	+	-
5	-	+	-
6	+	+	+
7	+	+	-
8	+	+	-

BTC, buccal mucosa-tongue side wall contact. +, BTC point formed. -, BTC point not formed.

Table 2. Findings of 2-way repeated measures ANOVA on ST and BUC thickness and ST/BUC ratio on axial images during mandibular rest

	ST Thickness			BUC Thickness			ST/BUC		
Measurement Site	**WAX (-)**	**WAX (+)**	**^{a}P**	**WAX (-)**	**WAX (+)**	**^{a}P**	**WAX (-)**	**WAX (+)**	**^{a}P**
SMC									
Mean	4.9	5.8		4.8	6.4		.88	.97	
±SD	1.6	1.3		1.4	1.3		.27	.33	
^{b}P					.014		.048		
^{c}P	.038	.014			<.001				
SMD									
Mean	7.1	5.4		5.0	4.0		1.8	1.4	
±SD	1.5	2.6		1.8	2.0		1.3	.37	
^{d}P									
RPC									
Mean	7.7	3.4	<.001	5.0	2.7	<.001	1.8	1.5	
±SD	2.4	1.2		1.3	1.3		.77	.68	

BUC, buccinator muscle; RPC, retromolar pad center; SD, standard deviation; SMC, second molar center; SMD, second molar distal; ST, submucosal tissue. Statistically significant differences found between following: ^{a}P for WAX (-) and WAX (+). ^{b}P for second molar center and distal. ^{c}P for second molar center and retromolar pad. ^{d}P for second molar distal and retromolar pad.

Table 3. Findings of 2-way repeated measures ANOVA on ST and BUC thickness and ST/BUC ratio of second molar center region on coronal images

Measurement Point	ST Thickness						BUC Thickness						ST/BUC					
	MR	PMo	MMo	^{a}P	^{b}P	^{c}P	MR	PMo	MMo	^{a}P	^{b}P	^{c}P	MR	PMo	MMo	^{a}P	^{b}P	^{c}P
Point A																		
Mean	3.0	2.0	2.3				4.3	3.5	3.0				.86	.67	.86			
±SD	1.0	.65	1.2				1.8	1.3	1.3				.62	.37	.57			
^{d}P	<.001	<.001	<.001				.012											
^{e}P		.012												.030				
Point M																		
Mean	6.0	6.1	5.4				6.6	5.2	4.5		.022		.96	1.4	1.3			
±SD	.71	1.6	2.1				1.9	1.9	1.7				.26	.89	.65			
^{f}P		.021	.008															
Point B																		
Mean	4.5	4.1	3.2				4.8	3.4	3.5				1.0	1.5	.95			
±SD	1.3	1.7	1.6				1.4	1.5	1.1				.43	.76	.54			

BUC, buccinator muscle; Mmo, midmouth opening; MR, mandibular rest; Pmo, partial mouth opening; SD, standard deviation; ST, submucosal tissue. Statistically significant differences found between following: ^{a}P for MR and PMo. ^{b}P for MR and MMo. ^{c}P for PMo and MMo. ^{d}P for Point A and M. ^{e}P for Point A and B. ^{f}P for Point M and B.

Table 4. Findings of 2-way repeated measures ANOVA on ST and BUC thickness and ST/BUC ratio of second molar distal region on coronal images

Measurement Point	ST Thickness						BUC Thickness						ST/BUC					
	MR	PMo	MMo	^{a}P	^{b}P	^{c}P	MR	PMo	MMo	^{a}P	^{b}P	^{c}P	MR	PMo	MMo	^{a}P	^{b}P	^{c}P
Point A																		
Mean	3.3	1.9	1.5				3.8	3.3	2.9				.93	.72	.57			
±SD	1.2	.94	.96				1.4	1.8	1.1				.35	.57	.41			
^{d}P	<.001	<.001	.001				.004	.002	.046									
^{e}P		<.001	.001												.004			
Point M																		
Mean	7.6	6.0	4.5		<.001		6.3	6.0	4.8				1.3	1.1	1.2			
±SD	1.4	1.8	1.8				1.8	1.9	1.9				.61	.58	.99			
^{f}P	.001	.036					.021	.008										
Point B																		
Mean	4.7	4.1	4.3				4.2	3.6	2.9				1.2	1.1	1.6			
±SD	1.7	1.6	1.9				1.1	1.1	1.2				.59	.39	.82			

BUC, buccinator muscle; Mmo, midmouth opening; MR, mandibular rest; Pmo, partial mouth opening; SD, standard deviation; ST, submucosal tissue. Statistically significant differences found between following: ^{a}P for MR and PMo. ^{b}P for MR and MMo. ^{c}P for PMo and MMo. ^{d}P for Point A and M. ^{e}P for Point A and B. ^{f}P for Point M and B.

WAX (+), the BUC thickness at SMC exhibited the same changes as the ST, with an increase of approximately 25% as compared with during MR with WAX (-). In contrast, the muscle width decreased by 25% in SMD and by >50% in RPC. For ST and BUC thicknesses in RPC, a significant difference was observed between WAX (-) and (+). A significant difference was observed between SMC and RPC for the ST/BUC ratio during WAX (-). The ST/BUC ratio during WAX (+) was higher the more posterior it was located.

Tables 3-5 show the results of 2-way repeated measures ANOVA on ST and BUC thicknesses and the ST/BUC ratio at point A, M, and B in SMC, SMD, and RPC on coronal sections during MR to PMo to MMo. The ST thickness tended to increase in each section in the order of point M>point B>point A. As was seen for the ST thickness, the BUC tended to increase in the order of point M>point B>point A. Comparison of the ST thickness in all sections at points A and M revealed significant differences during MR, PMo, and MMo. In terms of changes in the ST thickness during mouth opening at the same points, comparisons of point M in SMD and RPC during mouth opening indicated a significant decrease. BUC thickness significantly decreased during mouth opening at point M on SMC and RPC as compared with during MR. In SMC, SMD, and RPC sections, the ST/BUC ratio for point A was smaller than those of points M and B. Significant differences were observed for the ST/BUC ratios of points A and B during PMo in SMC and during MMo in SMD (P<.05).

DISCUSSION

The null hypothesis was rejected because ST and BUC thickness changed significantly when wax was added to the mandibular denture border and when mouth opening. In terms of MRI methods, T2 imaging, which has a long echo time with turbo spin echo was used to perform contrast imaging of the oral ST, which has a high moisture content. Because improving spatial and slice resolution lengthens the imaging time, thereby placing a greater burden on the participant, the participant

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Table 5. Findings of 2-way repeated measures ANOVA on ST and BUC thickness and ST/BUC ratio of retromolar pad center region on coronal images

Measurement Point	ST Thickness						BUC Thickness						ST/BUC					
	MR	PMo	MMo	${}^{a}P$	${}^{b}P$	${}^{c}P$	MR	PMo	MMo	${}^{a}P$	${}^{b}P$	${}^{c}P$	MR	PMo	MMo	${}^{a}P$	${}^{b}P$	${}^{c}P$
Point A																		
Mean	3.6	1.8	1.9				3.3	3.1	2.6				1.2	.59	.74			
±SD	1.9	1.2	1.1				1.5	1.2	.71				.67	.30	.47			
${}^{d}P$	<.001	<.001	<.001				<.001	.006	.020									
${}^{e}P$		.022					.042											
Point M																		
Mean	8.2	5.6	5.2	.007	.001		7.5	5.4	4.7	.018	.001		1.2	1.1	1.2			
±SD	1.6	2.3	1.9				1.8	1.5	1.4				.40	.71	.56			
${}^{f}P$	<.001		.028				.008											
Point B																		
Mean	4.6	4.0	3.1				5.2	4.4	3.9				.92	1.0	.85			
±SD	1.5	1.5	1.3				1.7	1.8	1.4				.28	.43	.41			

BUC, buccinator muscle; Mmo, midmouth opening; MR, mandibular rest; Pmo, partial mouth opening; SD, standard deviation; ST, submucosal tissue. Statistically significant differences found between following: ${}^{a}P$ for MR and PMo. ${}^{b}P$ for MR and MMo. ${}^{c}P$ for PMo and MMo. ${}^{d}P$ for Point A and M. ${}^{e}P$ for Point A and B. ${}^{f}P$ for Point M and B.

imaging burden was decreased by acquiring images in 5-mm slices. As a result of performing MRI that met the aforementioned conditions, the imaging time per axial and the complete coronal imaging session decreased to 78 seconds. As the MRI was made with the participants in the dorsal position, the tongue base may have been sunken. This tongue regression may have affected BTC formation on the MRIs.

The medial margins of the BUC maxillary and mandibular attachment regions or other measurement points were not used in the present investigation because the oral ST thickness at these areas was unclear because of artifacts and MRIs made 5 mm from the BUC medial margin in both the maxilla and mandible were the most straightforward to trace. Sealing by means of contact between the buccal mucosa and tongue on a denture base covering the retromolar pad was thought to be a physiological process necessary for completing the movement of the bolus in the retromolar pad in close contact with the tongue to the pharynx, whereby the buccal mucosa was pulled inward during swallowing.[2,3]

The BTC formation rate was approximately 81% on both the left and right sides among the 8 participants (Table 1). The reason the BTC point did not form in the remaining 19% was considered because the dorsal position during the MRIs caused the tongue base to sink, thereby cutting off contact with the buccal mucosa. The fitted dentures were created with the mandibular suction complete-denture fabrication method devised by an author (J.A.).[3] The 81% BTC formation indicated that dentures were shaped so that the retromolar pad was covered by the thin denture base with little effect on the posterior palatal seal. Meanwhile, as shown in Table 1, WAX (+) resulted in disruption of the BTC point in 86% of participants. This finding should be considered when making a clinical complete-denture impression. As these results showed, impression techniques attempting to expand the denture base to obtain unnecessarily expansive pressure-resistant areas because of a focus on functional recovery could impair BTC formation.

In WAX (-), the oral ST at each measurement site during MR was thicker the further posterior it was. However, no significant difference was observed in muscle thickness, and there were few differences in muscle width by site. Thus, it appeared that the thick oral ST, which is rich in fat tissue and located in the cheek area covering the retromolar pad, played an important role in BTC formation or in sealing of the posterior dentition. Because the main part of this tissue was located on the parotid duct and because the location differs from that of the buccal fat pad,[14] which extends along the upper part of the BUC anterior margin, it has not been the focus of previous research.

The comparison of WAX (-) and (+) indicated that the oral ST and BUC thickness decreased at SMD and RPC but increased in SMC. In particular, as a significant difference was noted in thickness after the addition of the wax, as compared with before, for oral ST and BUC thickness at RPC, the results indicated that when the wax caused pressure toward the outer buccal side, even greater morphological changes occurred in the oral ST and BUCs at this site.

During mouth opening the results showed that, although there was little morphological change in the maxillary BUCs for each section, marked morphological changes were observed in the mandibular BUCs. The oral ST, which was positioned above the BUC and was thicker the more posterior it was, appeared to be involved in this major morphological change. A common tendency for results being point M>point B>point A was observed for the oral ST and BUC thickness during MR in all coronal sections. The fact that several significant differences were revealed by comparisons of points A, M, and B in each coronal section also demonstrates that the oral STs, as well as the BUC thickness, differed at each site. Furthermore, comparisons of the oral ST and BUC thickness during mouth opening revealed a significant difference at point M in SMD during MR and MMo, as well as significant differences in RPC during MR and PMo and between PMo and MMo. Together, these observations demonstrated that mouth opening caused marked changes to occur in these thicknesses.

In terms of changes in the ST/BUC ratio during MR to PMo to MMo, there were significant differences between points A and B in SMC coronal head section during PMo and between points A and B in SMD during MMo, which demonstrated that oral ST and BUC thickness vary in accordance with the site.

Limitations of the research included that as the MRI scans were made at a single time point, it was impossible to examine the effect of longer term accommodation. To examine the changes of the thickness of soft tissue and muscle layer, a different experimental system is required, such as time-series MRI imaging from jaw rest position to mouth opening.

CONCLUSIONS

Based on the findings of this observational clinical study, the following conclusions were drawn:

1 When the denture base was intentionally expanded to the buccal side, the contact between the buccal mucosa and tongue on the retromolar pad was lost.
2 Axial images during MR showed that oral ST became thicker, whereas the ST/BUC ratio became higher the more posterior it was. Therefore, a sufficient thickness of the oral ST to the BUC was being maintained in the posterior dentition. When the buccal mucosa was pressed toward the buccal exterior side with wax, the shape of both the oral ST and BUCs tended to change easily.
3 In terms of morphological changes in the BUCs and oral ST on coronal images during mouth opening, the maxillary ST and BUCs were thinner than their mandibular counterparts and movement tended to cause few changes in thickness. The thickness of the oral ST and BUC in the maxillary and mandibular jaws differed by site. Furthermore, when the mouth was opened, these thicknesses changed in some sites, whereas the oral ST and BUC thickness changed at different ratios.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Jiro Abe: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing - original draft. **Soshi Hanawa:** Software, Validation, Data curation, Writing - review & editing, Visualization. **Keiichi Sasaki:** Supervision, Project administration.

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