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Volitional chewing with a conscious effort alters and facilitates swallowing during feeding sequence

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SUMMARY **The key objective of mastication is to form a food bolus suitable for smooth swallowing. However, chewing is usually performed without a conscious effort. Poor bolus formation can cause pharyngeal residue and suffocation in elderly individuals with reduced swallowing function. Therefore, chewing with a conscious effort may help the bolus to more easily pass the pharynx. This study aimed to clarify the impact of mastication with a conscious effort on the feeding sequence. Subjects included 25 dentulous volunteers who were informed and provided written consent. Lateral videofluoroscopy was performed during the feeding of solid agar jelly under two conditions: chewing naturally in their usual manner (without volition) and chewing with a conscious effort (with volition). Temporal evaluation was performed for mastication, stage II transport (STII), swallow onset and oropharyngeal transit time. Moreover, bolus volume at swallow onset and subjective evaluation of swallowing easiness were measured. Volitional chewing with a conscious effort lengthened the duration of the chewing sequence before and after STII and delayed the swallow onset despite the fact that the bolus volume in the vallecula and hypopharynx (HYP) had significantly increased. Furthermore, with volition, the bolus transit time from swallow onset in the oral cavity, upper oropharynx and HYP was reduced, and subjective evaluation of swallowing easiness demonstrated significant improvement. These results suggest that volitional chewing with a conscious effort can alter bolus transport and swallowing, resulting in easier swallowing.**

KEYWORDS: **mastication, deglutition, swallowing threshold, central pattern generator, videofluoroscopy, bolus**

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Introduction

Chewing food well is generally recognised as important for human health and may affect the nutritional status and quality of life of older people (1, 2). The key objectives of mastication are to pulverise food, mix the resultant food particles with saliva and aggregate the mixture into a bolus to swallow (3). Particularly for elderly individuals with reduced swallowing function, poor bolus transportation and formation caused by reduced masticatory function may increase the risk of pharyngeal swallowing disorders such as pharyngeal residue (4, 5). One possible compensatory method by which to improve bolus transportation and formation might be chewing with a conscious effort because mastication is usually performed with little conscious effort despite the fact that it can be performed voluntarily (6). Mastication is performed with the central pattern generator (CPG) located in the brain stem (7). However, it is also controlled by descending inputs from cortical masticatory areas (8) and modified by peripheral feedback from oral receptors (9). Moreover, activities of mastication and the swallowing centre may be interactive (8, 10). Thus, there is a possibility that masticatory and swallowing movements are consciously altered by volitional chewing.

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Hiiemae and Palmer (10) observed the feeding sequence of solid food using videofluoroscopy, which revealed close relationships between mastication and swallowing. The tongue actively transports the bolus from the oral cavity (OC) to the epiglottic vallecula before swallowing (stage II transport: STII), and the swallowing reflex is not evoked during mastication despite the fact that the bolus has already reached the epiglottic vallecula. Swallowing may be inhibited by mastication (8), and mastication may be subconsciously accommodated for swallowing to form an easily swallowable bolus (11). For instance, the number of chewing cycles until swallowing differs depending on the food property and volume (12). In addition, elderly individuals compensate for reduced masticatory function by increasing the number of chewing strokes until swallowing (13, 14). Therefore, we hypothesised that chewing with a conscious effort during eating might alter bolus transportation and swallow onset, helping to facilitate swallowing of the bolus. Indeed, Palmer *et al.* (15) revealed that the swallow onset could be consciously controlled by volition of restricted swallowing. However, the impacts of volitional mastication are not well known. The purpose of this study was to evaluate the impact of chewing with a conscious effort on the feeding sequence using videofluoroscopy in the same individuals with and without volition.

Methods

Subjects

The subjects included 25 dentulous volunteers (17 men, eight women; mean age, 27·6 ± 2·9 years) with normal occlusion. This study was approved by the Ethics Committee of Iwate Medical University School of Dentistry (Approval No. 01149). After a detailed explanation of this experiment both verbally and in writing, written informed consent was obtained from all subjects. All subjects were confirmed to have a certain level of reproducibility in the duration of the feeding sequence both with and without volition. The mean coefficient of variation in all subjects was 9·1% for the feeding sequence duration without volition and 10·9% with volition. All subjects were also confirmed to show the feeding sequence duration with volition almost twice as long as that without volition. The mean duration in all subjects was 13·6 s without volition and 25·0 s with volition. Masticatory performance was evaluated by colour-changeable chewing gum (Masticatory Performance Evaluating Gum XYLITOL*) using the same methods described by Sato *et al.* (11) to confirm that all subjects had almost equal masticatory function. Masticatory performance was represented by the colour difference (delta E: ΔE) between the chewed and unchewed specimens and revealed how efficiently the subjects could mix the gum. ΔE was calculated from L^*, a^* and b^* values measured by a colorimeter that constituted the CIELAB colour space. The mean ΔE among all subjects was 34·7 ± 7·2 for feeding without volition and 37·3 ± 5·4 with volition; these values represent average masticatory performance of dentulous adults with normal occlusion (11).

Videofluoroscopic swallowing study

Lateral view videofluoroscopy was performed at a rate of 30 frames/s using fluoroscopic diagnostic equipment (Sonialvision Safire II†) to observe the feeding sequence. Subjects were comfortably seated in an upright sitting position. A lead ball (6·85-mm diameter) was attached to each subject's neck for size calibration. The test food was a solid agar jelly (2 × 2 × 2 cm) containing 40% wt/vol barium sulphate. The agar jelly was made from 1·8 g of powdered agar (Kanten Cook‡), 12·0 g of sugar, 80 mL of water and 40 mL of barium sulphate. The agar jelly was placed on the subject's tongue, and he/she was instructed to eat it under two different conditions: 'eat by chewing naturally in the usual manner' (i.e. without volition) as the baseline and 'eat by chewing with a conscious effort' (i.e. with volition). Measurements were performed three times for both conditions after sufficient practice. The number of chewing strokes and the timing of swallowing were unrestricted.

Data analysis

Videofluoroscopic images were recorded onto a computer for the subsequent analyses. All images were blinded and randomised, then evaluated by an

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‡Ina Food Industry, Nagano, Japan.

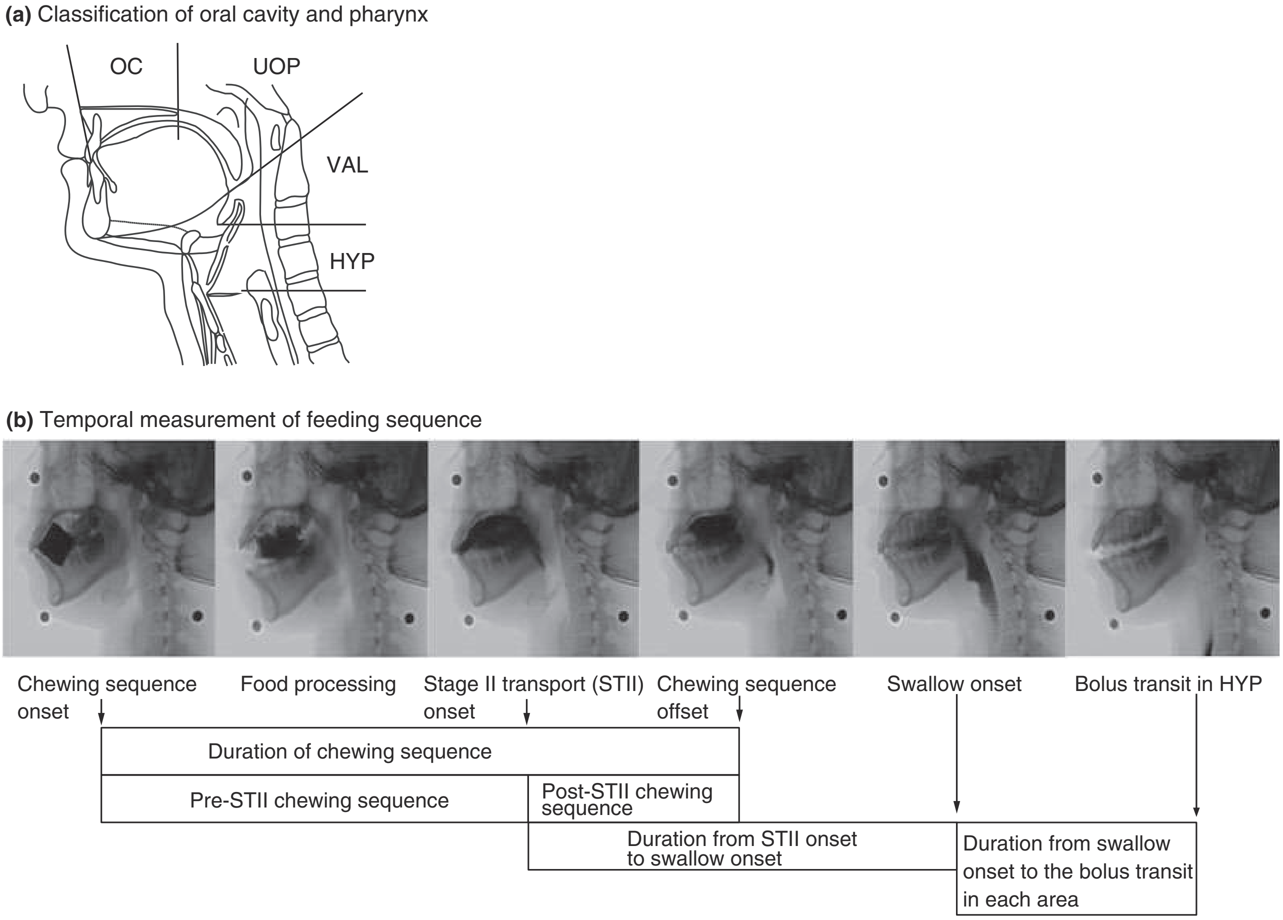

Fig. 1. (a) Oral cavity (OC) and pharyngeal areas were demarcated and labelled as follows (10, 15): the OC was from the anterior teeth to the posterior nasal spine; the upper oropharynx (UOP) was from the posterior nasal spine to the lower border of the mandible, extending posteriorly; the vallecula area (VAL) was from the lower border of the mandible to the base of the epiglottis, extending to the posterior pharyngeal wall; and the hypopharynx (HYP) was from the base of the epiglottis to the upper oesophageal sphincter. (b) Temporal analysis of the feeding sequence. The following measurements were performed. Duration of chewing sequence and duration of pre- and post-stage II transport (STII) chewing sequence: onset and offset of the chewing sequence was defined as first opening and final closure of the mouth during mastication, respectively; and STII onset was defined as the time at which the bolus was first clearly detected between the soft palate and the pharyngeal surface of the tongue (10, 15). Duration from STII onset to swallow onset: swallow onset was defined as the rapid elevation of the hyoid bone in an anterosuperior direction. Duration from swallow onset to bolus transit in each area: The duration from swallow onset to the posterior edge of the bolus leaving each area was evaluated.

examiner with more than 4 years of experience assessing videofluoroscopic swallowing study (VFSS). The OC and pharynx were classified into four areas based on previous studies that analysed bolus transport during the feeding sequence (Fig. 1a): oral cavity, upper oropharynx (UOP), valleculae (VAL) and hypopharynx (HYP) (10, 15). Video analysis software (Premiere Pro CS4 Extended[§]) was used to perform temporal analysis shown in Fig. 1b: (i) duration of chewing sequence and duration of pre- and post-STII chewing sequence: mastication onset was defined as the first opening of the mouth, STII onset was defined as the time at which the bolus was first clearly detected between the soft palate and the pharyngeal surface of the tongue (10, 15), and mastication offset was defined as the final mouth closure prior to the swallowing reflex. (ii) Duration from STII onset to swallow onset: swallow onset was defined as the rapid elevation of the hyoid bone in an anterosuperior direction. (iii) Duration from swallow onset to bolus transit in each area: the duration from swallow onset to the posterior edge of the bolus leaving each area

[§]Adobe, San Jose, CA, USA.

was evaluated to reveal the efficiency of bolus transit during pharyngeal swallowing. (iv) Proportion of bolus volume in each area at swallow onset: still images were obtained at swallow onset, and image analysis software (Photoshop CS4 Extended; Adobe) was used to measure the bolus volume in each area. With the sum of the bolus volume in all areas totalling 100%, the proportion of the bolus volume in each area was calculated according to the area of the lead ball visualised as size calibration.

To reveal the impact of volitional chewing with a conscious effort on swallowing ease, subjective evaluation of swallowing easiness was performed with a visual analogue scale (VAS) for each feeding. A VAS is often used as a measure of patients' perception of their swallowing abilities (16, 17). In this study, the VAS was a 100-mm horizontal line with the left being 'the most difficult swallowing imaginable' (0 mm) and the right being 'the easiest swallowing imaginable' (100 mm).

To detect intra-individual differences with and without volition, statistical analysis was performed using statistical software (SPSS Statistics ver. 20[¶]), and the level of significance was set at 5%. The duration of the post-STII chewing sequence, duration from STII onset to swallow onset, bolus volume and VAS score were not normally distributed; thus, they were analysed by the Wilcoxon signed-rank test as a nonparametric method. Other data were normally distributed, so they were analysed by the paired *t*-test.

Results

In the VFSS images of all subjects, the tongue movement used to push the bolus forward from the UOP into the OC was more pronounced with than without volition. The chewing sequence within each individual was reproducible and less varied. Each subject performed mastication with volition for almost twice as long as that without volition. Figure 2 shows that the duration of the chewing sequence with volition was significantly longer than that without volition ($P < 0{\cdot}001$). The durations of the pre- and post-STII chewing sequences with volition were also significantly longer than those without volition ($P < 0{\cdot}001$). Figure 3 shows that the duration from STII onset to swallow onset with volition was significantly longer than that without volition ($P < 0{\cdot}001$). Figure 4 shows each duration from swallow onset to bolus transit in the OC, UOP, VAL and HYP. Although the duration in the VAL showed no significant change, the durations in the OC, UOP and HYP with volition were significantly shorter than those without volition (OC, $P < 0{\cdot}001$; UOP, $P = 0{\cdot}045$; VAL, $P = 0{\cdot}206$; HYP, $P = 0{\cdot}005$). Figure 5 shows the bolus volume at swallow onset. The bolus volume in the OC was significantly smaller and that in the VAL and HYP was significantly larger with than without volition (OC, $P = 0{\cdot}009$; UOP, $P = 0{\cdot}135$; VAL, $P = 0{\cdot}018$; HYP, $P = 0{\cdot}043$). Regarding the subjective evaluation of swallowing easiness, the VAS score with volition was significantly higher than that without volition ($P < 0{\cdot}001$) (Fig. 6).

Discussion

The key purpose of this study was to reveal the impact of volitional chewing with a conscious effort on the natural feeding sequence. We performed a VFSS, focusing the intra-individual differences in all subjects with versus without volition. Therefore, the duration of the chewing sequence and swallowing timing were not restricted. Restriction would have resulted in masticatory and swallowing movements that differed from the subjects' usual movements (15).

Although each subject had an individual swallowing threshold, they showed high reproducibility under each chewing condition. The duration of the chewing sequence was significantly longer (almost twice as long) with than without volition in all subjects. The bolus was usually propelled to the VAL by STII during mastication, which is an active tongue 'squeeze back' movement (10). However, volition causes the tongue to push the bolus forward from the UOP into the OC for optimal bolus formation, which may inhibit STII and increase the duration of the pre-STII chewing sequence. This tongue 'push-forward' movement is more frequently observed from mastication onset to swallow onset with than without volition. At the same time, the duration from STII onset to swallow onset was significantly longer with volition, suggesting that the swallow onset is delayed with volition despite the fact that STII has already occurred. Therefore, a greater bolus volume was finally transported

[¶]IBM, Tokyo, Japan.

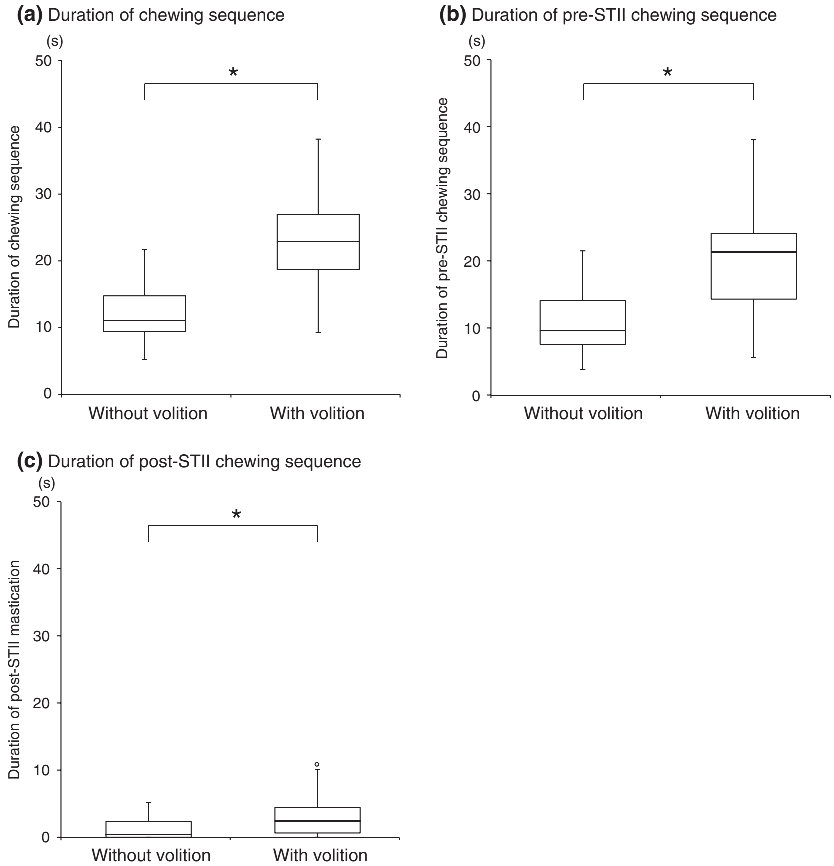

Fig. 2. (a) Duration of chewing sequence, (b) duration of pre-stage II transport (STII) chewing sequence and (c) duration of post-STII chewing sequence. All durations were significantly longer with volition (*$P < 0{\cdot}001$). The circle indicates an outlier. The box comprises the median and the first and third quartiles. The whiskers represent the maximum and minimum values.

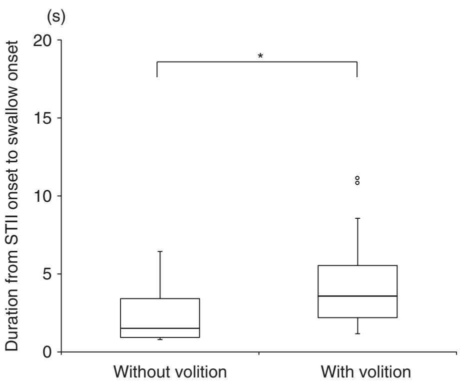

Fig. 3. Duration from stage II transport (STII) onset to swallow onset with volition was significantly longer than without volition (*$P < 0{\cdot}001$). The box comprises the median and the first and third quartiles. The whiskers represent the maximum and minimum values. The circles indicate outliers.

from the OC to the VAL despite the occurrence of the tongue push-forward movement. Saitoh *et al.* (18) suggested that the reduction in the posterior tongue–palatal seal during chewing motion causes spillage from the OC into the pharynx. In general, while eating a solid food, swallowing is easily evoked when a certain bolus volume enters the VAL and HYP. In the present study, however, the increased bolus volume in the VAL of almost all subjects and HYP of some subjects due to the longer chewing duration did not trigger the swallowing reflex, suggesting that another factor is involved in swallowing inhibition, such as volition as a central control of swallowing by the cerebral cortex.

The swallowing reflex is evoked not only by afferent input from receptor organs in the pharynx as a spontaneous action, but also by commands from the cerebral cortex as a voluntary action. Orders from the cerebral cortex under a volitional condition may have a direct inhibitory effect on the deglutition centres. Palmer *et al.* (15) reported that STII and swallow onset were delayed by volition to swallow. Subjects were allowed to swallow only at the examiner's command, even when ready to swallow; therefore, volition changed both the timing of swallow onset and bolus location before swallowing. Although the subjects in the present study were allowed to swallow at

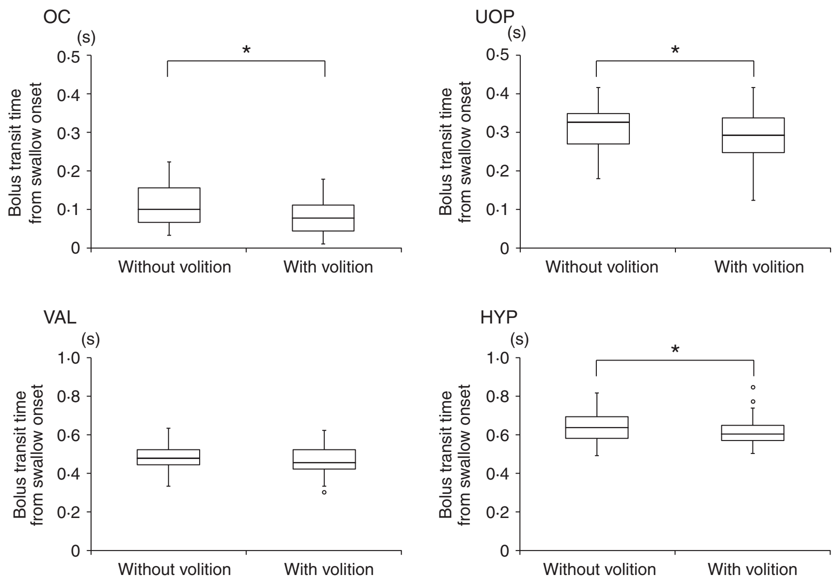

Fig. 4. Duration from swallow onset to bolus transit in each area. The transit time through the oral cavity, upper oropharynx and hypopharynx was significantly shorter with volition than without volition (*$P < 0{\cdot}05$). The box comprises the median and the first and third quartiles. The whiskers represent the maximum and minimum values. The circles indicate outliers.

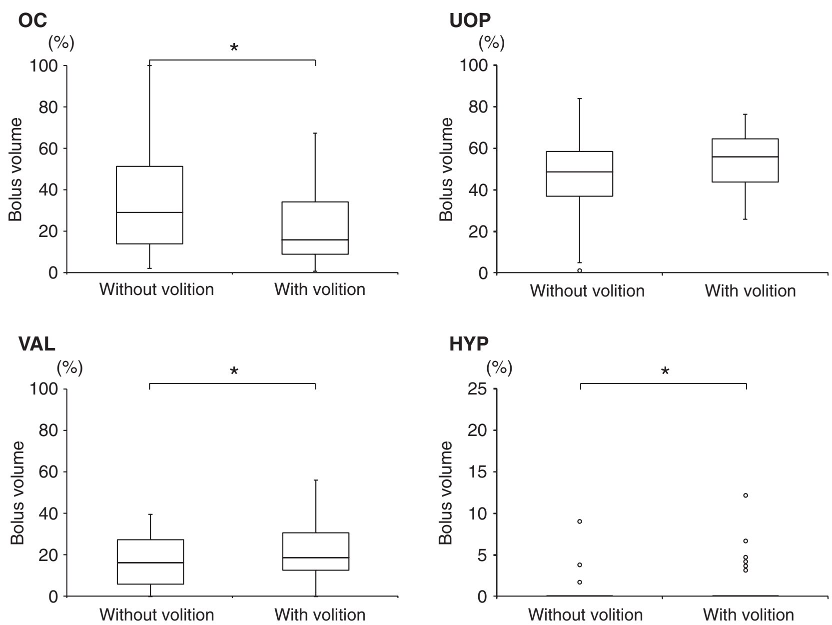

Fig. 5. Proportion of bolus volume in each area at swallow onset. Bolus volume in the oral cavity was significantly smaller and that in the valleculae and hypopharynx (HYP) was significantly larger with than without volition (*$P < 0{\cdot}05$). The box comprises the median and the first and third quartiles. The whiskers represent the maximum and minimum values. Bolus volume in the HYP was 0% in most subjects; therefore, the circles indicate outliers in the box plot.

their will, our findings support volitional control of swallowing described by Palmer *et al.* (15), suggesting that volitional mastication delayed both STII and swallowing onset and that swallowing can be controlled by changing mastication. However, whether mastication directly inhibits swallowing remains debatable. In animal experiments, activity in the mastication centre has been found to either inhibit or facilitate activity in the deglutition centre (8, 19, 20). Tsujimura *et al.* (8) suggested that the swallowing reflex is inhibited by cortical masticatory areas or via the masticatory CPG. Volitional chewing with a conscious effort directly and positively influences the masticatory centre to maintain mastication and negatively influences the deglutition centre via the masticatory CPG, inhibiting the swallowing reflex (8).

The cerebral cortex may modulate the initiation of the swallowing reflex, which is programmed by the CPG, but not sequential swallowing (8, 15). Thus, volition by the cerebral cortex may affect the initiation of pharyngeal swallowing, but not the entire swallowing movement. In this study, the VAS score

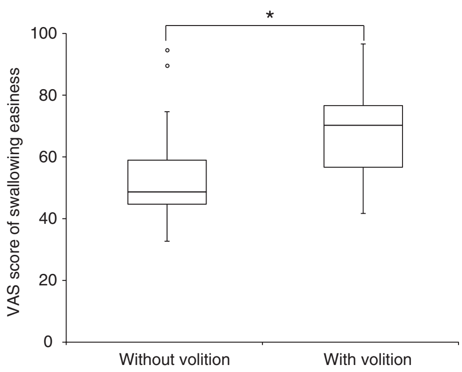

Fig. 6. Subjective evaluation of swallowing easiness by a visual analogue scale (VAS). VAS scores were significantly higher with than without volition (*$P < 0{\cdot}001$). The box comprises the median and the first and third quartiles. The whiskers represent the maximum and minimum values. The circles indicate outliers.

of swallowing easiness was significantly higher when feeding with volition; this may have been caused by changes in bolus transportation and/or bolus properties because the pharyngeal swallowing movement may not change with volition. The bolus transit time after swallow onset in the OC, UOP and HYP was significantly shorter with volition than without volition. In particular, the rapid transit of a bolus through the HYP may be important in preventing aspiration during swallowing. The observed reduction in transit time through the OC and UOP could have been a result of a reduced bolus volume in the OC. Chewing with a conscious effort can transport a greater bolus volume to the pharynx significantly in advance of swallowing, which may result in more efficient transport during pharyngeal swallowing. Another possible explanation for the improved VAS score would be the bolus properties. To swallow easily, the bolus must be pulverised into acceptable particle sizes, aggregated into a mass and mixed with saliva by mastication to become cohesive, smooth and plastic (3–5, 14). To achieve such bolus properties, saliva is very important (21, 22). Kim *et al.* (22) suggested that a greater number of chewing strokes is needed to swallow among patients with stroke who have reduced saliva volumes. van der Bilt *et al.* (23) reported that adding fluid to dry food significantly reduced the number of chewing strokes until swallowing. Volitional chewing may also result in higher salivary flow and a more sufficient amount of time to form a safe and easily swallowable bolus by mastication, even if the longer duration of mastication does not contribute to a reduction in particle size (24).

The subjects in the present study were dentulous adults. To reveal how mastication with a conscious effort improves reduced swallowing function, further study of patients with dysphagia is needed. In addition, there were interindividual variations in the duration of the feeding sequence. Moreover, the bolus volume, properties, and tongue and hyoid movements (25) may also be related to swallowing easiness; however, we did not evaluate these factors in the present study. Further studies are needed to reveal the detailed impacts of chewing with a conscious effort on the feeding sequence.

Conclusion

Volitional chewing with a conscious effort lengthened the chewing sequence duration, inhibited STII and delayed pharyngeal swallowing despite the fact that a greater bolus volume was transported from the OC to the pharynx. It also reduced the bolus transit time after swallow onset in the oral and pharyngeal areas and improved swallowing easiness. These results suggest that volitional mastication can alter bolus transport and swallow onset during the feeding sequence of a solid food, thereby enabling smooth bolus transit.

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Conflict of interests

No conflict of interests declared.

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