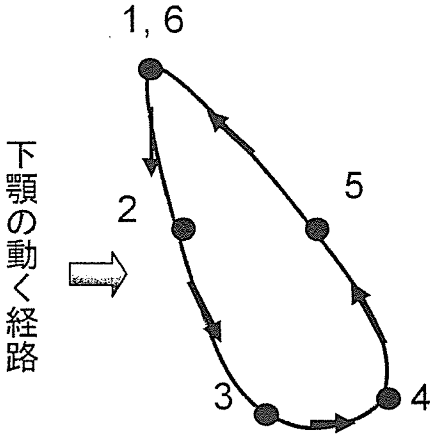
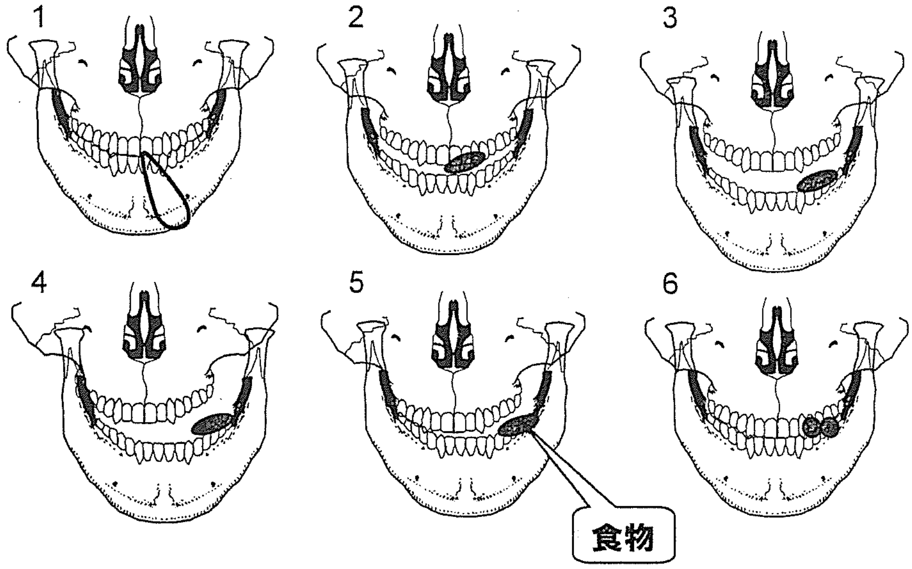
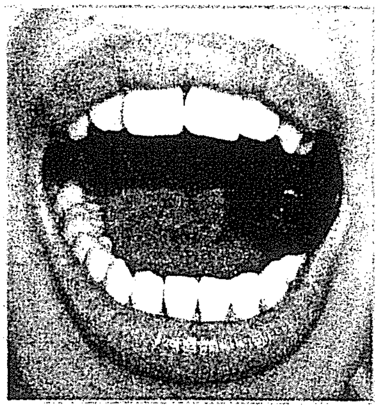
ふんさい　そしゃく

食物の粉砕（咀嚼）



1. 顎を閉じる
2. 顎を右（ または 左）に
   ずらしながら開ける
3. 食物を歯の間に入れる
4. 食物を上下の歯でとらえる
5. 食物をすりつぶす
6. 再びあごを閉じる
   （食物は粉砕される）





奥歯（臼歯）もあごと一緒に動き食物をすりつぶします．

鏡で食べるところを見てみましょう．咀嚼するとき，顎は単に開閉するだけではありません．奥歯（臼歯）で食物をすりつぶすため，少し右または左に膨らんだ楕円運動（図示）をします．
このとき膨らんだ側の歯が食物を粉砕します．

この複雑な動きをあなたは考えて食べていますか？
実はこの複雑な運動プログラムは脳にあり，たとえば新聞を読みながらでも，意識せずにできるのです．

唾液（だえき）の働き

口の中を洗い流し
殺菌してくれます.

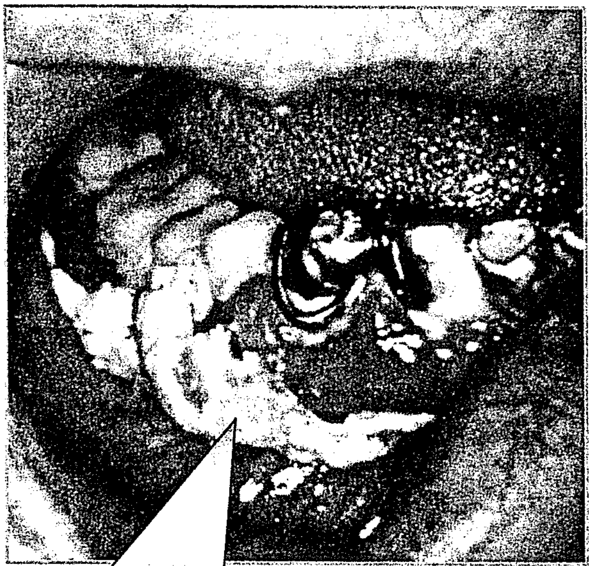
1日に約1.5リッター
も出ています.

消化酵素など消化を助け
る成分が入っています.

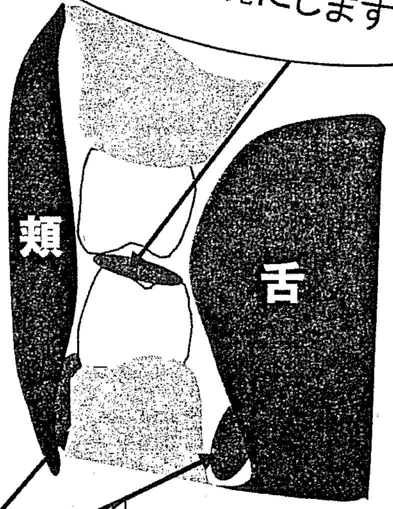
咀嚼時，**舌**は食物を唾液と混ぜるようにかき混ぜます.
このため，**食物の味**を十分感じることが出来ます.
また，**噛む**ことが刺激となって**唾液**もよく出てきます.

注意！ 病気や薬が
原因で唾液の出が
悪くなることがあります.

緊張すると**ネバネバ**した唾液が出ます.
ゆったりした気分でおいしく食べると
サラサラした唾液が出てきます.



注意！ 歯と頬，歯と舌の間に
食物がたまりやすいので食後
口の中をきれいにしましょう.

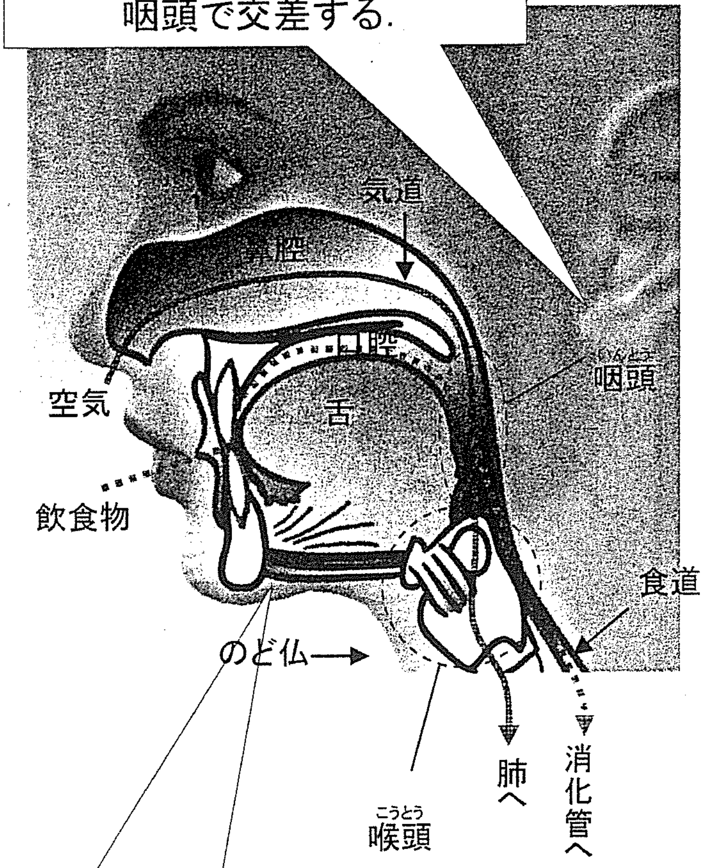


食物を噛むことで粉砕し
唾液と混ぜて飲み込み
やすい食塊にします.

唾液が出なくなると
こんなところが汚れます.

嚥下（飲み込むこと）

食物の通路（食道：赤点線）と
空気の通路（気道：青線）が
咽頭で交差する.



嚥下ってなんですか？

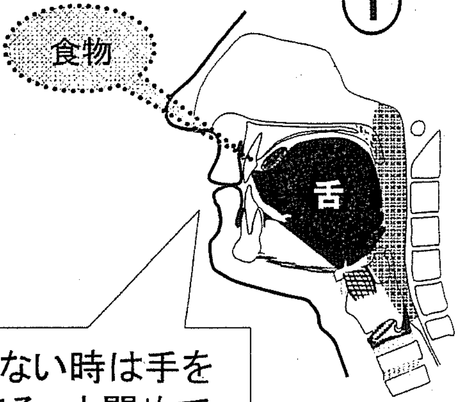
いつもは‘のど’の奥（咽頭）は鼻から入った空気を喉頭・気管を経て肺に送る通路になっています．しかし，食事中は口から入った食物を食道に送る通路になります．咽頭は空気と食物の通り道で，嚥下はその交通整理をしています．

唾液を飲んでみてください．‘ゴックン’と飲み込むとき，のど仏が上にあがります．これは唾液や食物が咽頭から食道に送り込まれる際，誤って気管に入らないように喉頭が持ち上がって，気管の入り口にふたをしたのです．加齢や脳卒中の後遺症でのどの周りの筋肉の力や動きが悪くなると食物が気管に落ちて，‘むせ’ます．

嚥下の順序

①

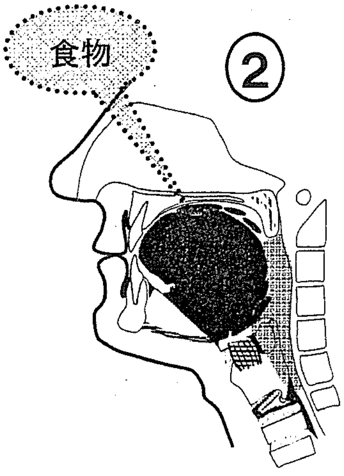
唇を閉じて，舌が食物をすくい上げます．



閉まらない時は手を添えてそっと閉めてあげてください．

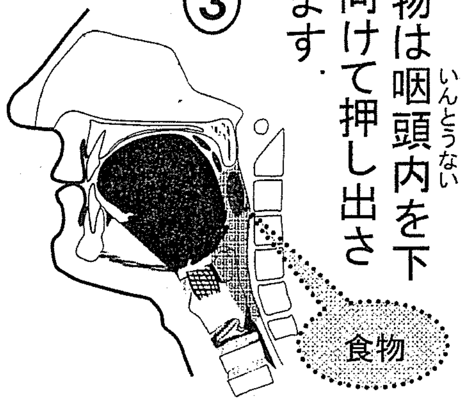
②

軟口蓋（なんこうがい）は持ち上がり，舌が食物を咽頭に押し込みます．



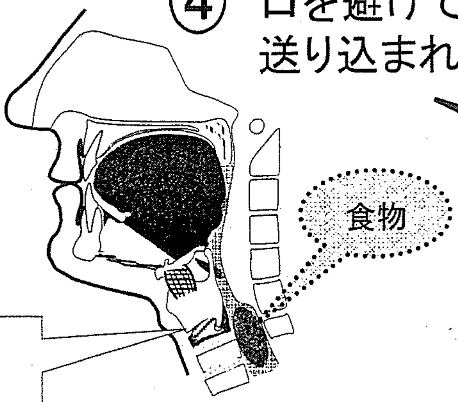
③

食物は咽頭内（いんとうない）を下に向けて押し出されます．



④

食物は気管の入り口を避けて食道に送り込まれます．



のど仏が上がります．

ここまで**1秒**かかりません．

失敗すると食物が気管に入ることがあります．

（誤嚥）

上手に食べられない、飲み込めない

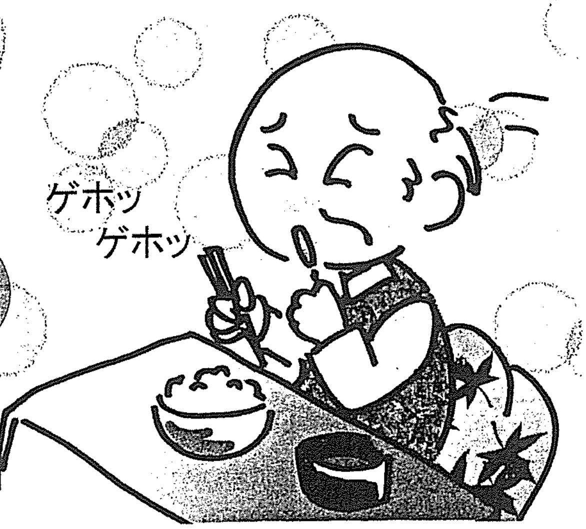
咀嚼や嚥下は，健康なら意識しなくてもできます．しかし，加齢や脳卒中などで感覚が鈍ったり，筋肉が上手に動かせなくなると「食べようとしない」「食物を上手に口に運べない」「上手に噛めない」「飲み込めない」といったさまざまな障害が出てきます．このような症状を‘**摂食・嚥下障害**’とよんでいます．

放っておくとどうなるの？

食欲がなくなり栄養が不足します．

水分が不足すると血液が固まり易くなります．

食べることが苦痛になり，楽しみの一つが失われます．



さらに

食物が気管や肺に入ることを‘**誤嚥**’とよび，

1．むせます．
2．息が苦しくなります．（時には窒息します．）
3．食物が細菌を運んで，肺炎になることもあります．

むせないといって安心しないで，むせる元気もない人もいます．

食事中むせたり，食後元気がなくなったり，風邪でもないのに熱が出るようなら，専門家に相談しましょう．

重要なことは原因を突き止めることです．

どうすればよいのでしょうか？

要介護者の状態
を正しく知る，
そして

専門家に相談
しましょう

- 食品の物性や調理方法の工夫
- 食べやすい食材の選択
- 体の向きや角度など姿勢を調節
- 食事の介助方法を工夫

好きなものを好きな人と楽しく食べることが重要です．

まず，お腹が減っているか，確認を

口腔ケア

注意！
口の中が汚いと，食事がまずい上に，**肺炎**などの病気の危険性が増えます．

食前，食後に楽しくお口の中を**清掃**しましょう．

とろみ増粘剤

注意！
水は流れが良いので，**誤嚥**し易い食物です．

ビールやお酒も対象となります．

調理の工夫

包丁の入れ方ひとつで噛みやすくなります．

注意！
好きなものは食べやすく，**嫌いなものは食べにくい**

見た目，匂い，味，歯ごたえなど，おいしさの要素を考えてください．
温度もおいしさの一つです．

介助の工夫

注意！
なるべく**上体を起こし**，食事にあった清潔な環境で，ゆっくり，楽しく

寝た姿勢は食べにくく**誤嚥**を招きます
腹に重い布団はのっていませんね！

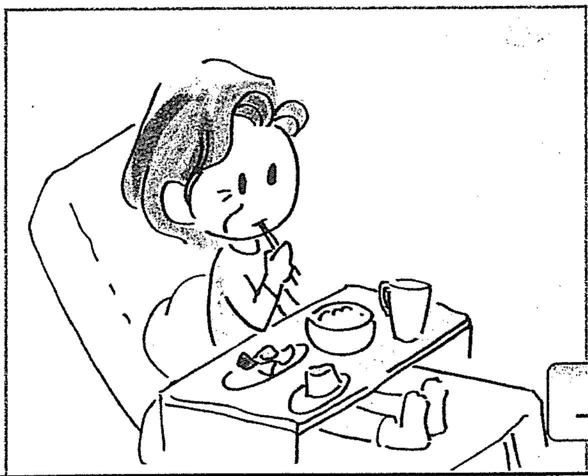
浅いスプーンで**少量**ずつ，口に残っていないか確認しながら

楽しい食事の場つくりをしましょう

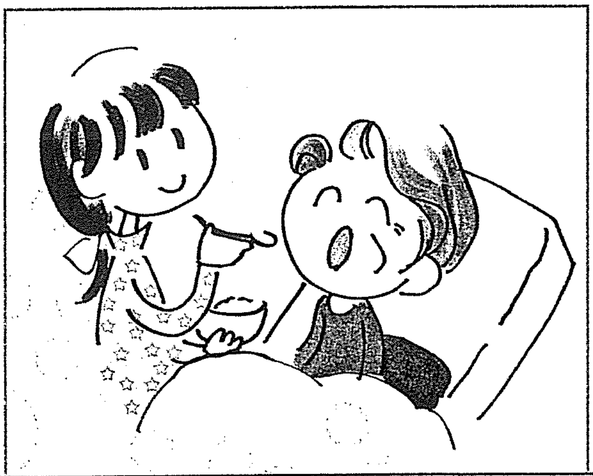
食事介助の必要な高齢者には，
食べる意欲を引き出すために，
いろいろな工夫が求められます．
高齢者がどんな食事を
“**食べたい**”と望んでいるのかを
考えて下さい．

1．皆で一緒に楽しい食事環境をつくりましよう．
2．食卓に季節感（**旬**の素材，季節の**花**など）を演出してみましょう．
3．食器の色や形，食事の盛り付けに配慮しましょう．
4．本人の食べたいもの，好きな物を出しましょう．
5．食事時間を十分にとりましょう．

食べるときの**姿勢**も重要です．



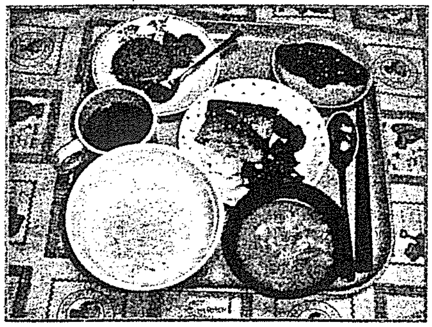
ベッドの上やイスに座っての食事姿勢



上半身を起こし頭（首）を前屈した食事姿勢

用語の解説

頁	用語	解説
1	栄養・代謝	食物として体に取り入れられた栄養は化学反応を利用して分解されたり，必要な物質に組み替えられたりします．これを代謝と言います．筋肉を動かすときのエネルギーも代謝によって作られます．
3	食物の認知	人は食物を食べる前に，見た目や匂いで食べられるかどうかを確認します．これを食物認知と言います．
	そしゃく 食物の粉砕（咀嚼）	硬い食物や大きな食物は，歯で噛み砕き細かくします．この口の働きを咀嚼と呼び，このときに食物は唾液と混ぜられて飲み込みに適したかたまり（食塊：しょっかい）になります．
	えんげ 飲み込み（嚥下）	食物や飲料水を’ゴックン’と飲み込むことを嚥下と言います． このとき‘のど仏’が動き，食物を食道に送り込みます．
	せっしょく 食べること（摂食）	口から食物を食べることを摂食と言います．



頁	用　語	解　　説
8	加齢	人の誕生・発育・成長・老化の過程を，加齢と言います．
11	食品の物性	食物の味や匂いは化学的な性質により決まります．一方，硬さ・ネバっこさ・くっつきやすさなど，物理的性質を食品の物性と言います．
	口腔（こうくう）ケア	お口の中を清掃すると同時に，筋肉や皮膚に刺激を与えることです．食べ物の残りかすや細菌のかたまりを取り除くことで，肺炎の防止になります．筋肉や皮膚をこすったり動かすことで運動・感覚機能が増進します． 専門的には， 1）歯石の除去 2）義歯の手入れ， 3）摂食・咀嚼・嚥下訓練 などもあります．
	専門家	摂食・嚥下障害を専門にしている医師・歯科医師が近くにいない場合には，近くの歯科・耳鼻科・リハビリテーション科の先生に紹介してもらいましょう．

在宅介護者のハンドブック
在宅介護の食事介助マニュアル　＜基礎編＞

2006年12月　発行

厚生労働科学研究・長寿科学総合研究事業
「安全でおいしい新嚥下補助食を利用した家庭や介護施設における
食事介助の在り方に関する研究」
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Oral behavior from food intake until terminal swallow[☆]

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Abstract

We analyzed oral behavior from food intake until terminal swallow for mastication and swallowing under a freely eating condition with a natural food. Measurements, including movement of the mandible and tongue, the size of the gape, different sequences involved in the oral aspect of the swallowing action, and bolus size and movement were carried out in five "freely eating subjects" using videofluorography. During food intake, the tongue moved forwards and backwards to introduce food into the mouth, to compress the food against the hard palate, and to transport food to the occlusal surface of the molar teeth. Most of the food was swallowed in the first swallow, and any residual food was aggregated by the tongue into a bolus and then swallowed in the last swallow. These findings suggest that 1) tongue manipulation plays an important role in recognizing and evaluating the volume of bite taken, 2) the intra-oral compression of food has a role in the recognition of food texture, 3) stage I transport is closely bound to the texture recognition process, 4) humans need at least two swallows, even with one bite of food, when ingesting food freely, and 5) the duration time of the oral stage of swallowing may depend on the bolus volume and be longer for smaller volumes unlike those measured under the command swallow.

Keywords: Food intake; Natural bite; Natural swallowing; Mandibular movement; Freely eating subjects

1. Introduction

Swallowing mainly occurs during eating, and thus is part of a continuum of feeding behaviors, which include food intake into the mouth, mastication, oral food transport, and swallowing [1,2]. However, ever since Magendie [3] introduced the concept of swallows to include oral, pharyngeal, and esophageal stages, swallows have been mostly regarded as an isolated behavior from mastication, and swallow-related events were studied in the command swallow [4,5].

In a study using videofluorography (VFG) and electromyography, Palmer et al. [6] reported that part of the food entered the oropharynx prior to swallow onset, while most of the food was still in the oral cavity at swallow onset. Based on these results, they applied the concept of stage II transport, which was defined in an animal study [7], to humans. Interestingly, stage II transport may be inhibited when subjects keep test food in the mouth until an examiner allows them to swallow (command swallow) [6]. Thus, it may be expected that swallows during a complete feeding sequence in humans differ from the command swallow.

In order to understand the coordination of mastication, oral food transport, and swallowing, swallows have been studied during the complete feeding sequence in humans [1,6,8,9] and animals [10,11]. Hiiemae and Palmer [9] have reported the intra-oral food management for solid food as follows, i.e. the masticatory sequence has four main components: (1) stage I transport, in which food is ingested and positioned on the occlusal table if reduction is required; (2) processing, in which trituration occurs; (3) oropharyngeal accumulation time, in which food ready for bolus formation is moved distally through the fauces (stage II transport) although processing may

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[☆] This work was based on a thesis submitted to Niigata University Graduate School of Medical and Dental Sciences as part of a PhD degree.

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continue; and lastly, (4) hypopharyngeal transit time, in which the bolus is swallowed. However, previous human studies were carried out with fixed amounts of food under rather restricted conditions for food intake. Thus, their findings should be confirmed under freely eating conditions with natural food.

The mode of mastication of soft foods (agar and gelatin gels) was examined by Arai and Yamada [12] in humans. They found that there were two types of management modes and that the mode altered from compression with the tongue and hard palate to shearing with the dentition as the hardness of the model samples increased. The thresholds of hardness were 0.08 kg for the agar gel and 0.03 kg for the gelatin gel. Visual analysis of VFG revealed that the food texture may be recognized by initial compression (deformation rate: about 12%) between the tongue and hard palate around the incisive papilla. They concluded that the mastication mode of a food either by compression or shearing may be determined according to the texture, and that the process of initial compression of food is the first step of texture recognition. Although this study may have introduced a very important phenomenon, it was carried out with artificial foods, and no other study has since confirmed this. Thus, it is now necessary to examine the texture recognition process in studying under natural feeding condition.

Swallows affect both respiration and mastication. McFarland and Lund [13] investigated interactions among respiration mastication and swallowing to study the neural mechanism underlying oral motor behavior in humans. They then observed three characteristic swallowing patterns, i.e. interposed, terminal, and spontaneous swallows. The interposed swallow occurred within chewing cycles, while the terminal swallow ended the masticatory sequence. On the other hand, most masticatory sequences end with a period characterized by irregular jaw movement and a swallow. Hiiemae et al. [14] and Palmer et al. [15] named the whole process 'clearance,' which is a process to aggregate food particles from the mouth including buccal vestibules. However, in the aforementioned studies, no attempt was made to apply quantitative analysis to these different sequences of the oral part of the swallowing action during complete feeding sequences. In addition, there is some disagreement regarding the terminology used, such as 'masticatory sequence' vs. 'feeding sequence' and 'terminal swallow' vs. 'clearance,' among investigators which is largely dependent on their respective research areas. This indicates the need for a quantitative study on the complete sequence from food intake to the swallow.

The aims of the present study were 1) to learn how 'normal' food was managed in the mouth throughout the feeding sequence, 2) to analyze oral behavior during food intake, and 3) to characterize, quantify, and compare interposed and terminal swallows in freely eating human subjects using videofluorography (VFG).

2. Materials and methods

2.1. Subjects

Five healthy adults (two females and three males, average age: 21±2 years) participated in this study. None of the subjects had a history of major medical problems, including dysphagia. Informed consent was obtained from all subjects and the study protocol was approved by the Ethical Committee of the Niigata University Faculty of Dentistry in accordance with the Helsinki Declaration.

2.2. Data collection

The feeding events in the subjects were observed using a VFG (MULTISKOP; Siemens-Asahi Medical Technologies Ltd., Tokyo, Japan) installed at Niigata Medical and Dental Hospital. The technical parameters for the VFG settings were as follows: speed: 25 frames/s; focus size: 1.0 mm; working voltage: 74 kV; working current: automatic control; and distance between subject and detector: 60 cm. Using these settings, the VFG exposure time was limited to a maximum of 2 min/subject, and the total radioactivity exposure/subject was estimated to be equivalent to approximately 10 dental X-ray exposures [16].

The test food was a stick of sushi rice with a small amount of barium powder (diameter, 25 mm; length, 100 mm; weight, 50 g), which could be handled by hand. Radiopaque markers (1 mm diameter lead balls) were glued to the buccal surfaces of the upper and lower incisors to measure the jaw gape. A calibrator (20 mm long lead bar) was attached between the nose tip and the upper lip and was used to calculate the actual dimensions and movements of the organs on the VFG images. During the recording, each subject sat on a stool and turned laterally to the image intensifier. Each subject was instructed to hold their head in a neutral position, and no cranial constraints were used. Each subject was asked to take a single natural bite of test food, which they were then required to chew and swallow naturally until it was cleared from the mouth. A recording session began when the subject moved their hand to bring the food to the mouth, and it ended when all the food was cleared from the mouth. The time when all the food was cleared from the mouth was indicated by the subjects by raising a hand. The test was repeated three times per subject.

2.3. Data analysis

To determine the weight of one bite of food, the amount of the given food remaining after the subject took one bite was weighed to determine the amount of food that had been bitten off. VFG images were recorded on a digital video recorder (DCR-TRV10; Sony), and each recording was immediately replayed at a slower speed for review by two experienced investigators. The recording was judged as acceptable if the image was of good quality, head movements were minimal, and a complete feeding sequence was included. The VFG recordings were then examined frame-by-frame by direct visual observation using the stop-frame/slow-motion function of the video recorder. The mandibular movement trajectory with time was reconstructed from the distance between the lead balls on the recording images using a software program (Micro Analyzer; Japan Poladigital Inc., Tokyo, Japan) for each subject (Fig. 1). A chewing cycle was defined as the period from one maximum jaw opening to the next, and was divided into three

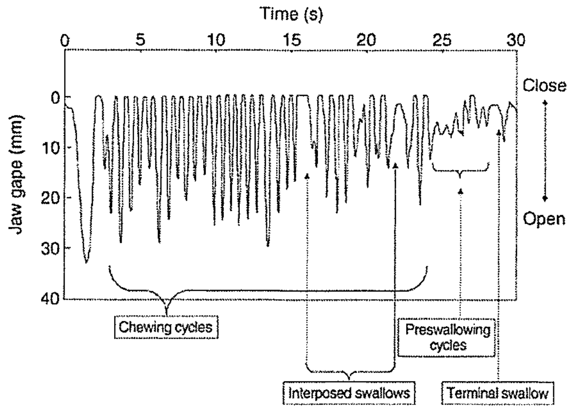

Fig. 1. Mandibular movement trajectory with time generated from VFG images during a complete feeding sequence. Chewing cycles: the mandible moved rhythmically following three phases (closing, occlusal, and opening). Interposed swallows: occurred once or twice within the chewing cycles. Preswallowing cycles: the maximum gape decreased, and small irregular mandibular movements were seen. Terminal swallow: occurred at the end of the sequence.

phases; closing (CL), occlusal (OC), and opening (OP), on the basis of the directional changes in mandibular movement (Fig. 2A). The CL phase began at the maximum jaw opening and ended at the uppermost jaw position. The OC phase followed the CL phase and was defined as the period within a chewing cycle during which there was no measurable change in

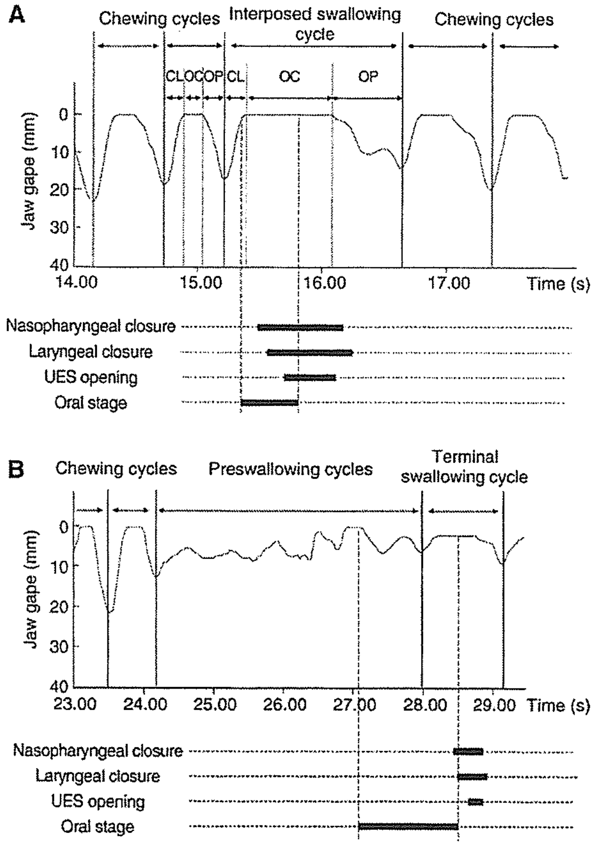

Fig. 2. Temporal relationships among mandibular movements and swallow-related events during interposed and terminal swallowing cycles. (A) Three phases (CL: closing; OC: occlusal; OP: opening) were identified in the chewing and interposed swallowing cycles. (B) Preswallowing cycles followed the chewing cycles and preceded the terminal swallowing cycle. Preswallowing cycles were characterized by a decrease in the maximum gape and irregular small mandibular movements. The jaw gape in the terminal swallowing cycle was similar to that in the preswallowing cycles. Thick bars indicate the interval of each swallow-related event: nasopharyngeal closure, laryngeal closure, UES opening, and the oral stage of swallowing. Dotted vertical lines indicate the onset and offset of the oral stage of swallowing.

the distance between the upper and lower jaw. The OP phase followed the OC phase and ended at the subsequent maximum jaw opening. Consequently, the duration of each phase and total cycle duration were analyzed.

Swallowing was identified on the basis of the following events: nasopharyngeal closure, laryngeal closure, and upper esophageal sphincter (UES) opening. Onset and offset of these events were obtained from the VFG images by direct visual observation, and the duration of each event was analyzed. Cycles involving these events were termed swallowing cycles and distinguished from the chewing cycles (Fig. 2A). Swallowing cycles were divided into phases, as were the chewing cycles, and the total cycle duration and duration of each phase were consequently analyzed. In the case of swallowing cycles, the timing of the movement of the tongue tip against the anterior of the hard palate just prior to swallowing was determined [17]. This tongue movement may represent the onset of the oral stage in swallows. Therefore, we examined the duration of the oral stage of swallowing on VFG images as the time interval between movement of the tongue tip toward the anterior of the hard palate just prior to swallowing and movement of the bolus tail passage over the fauces, as reported previously [17–19]. The bolus volume in each swallow was estimated as the area of food bolus on the VFG image at the time of passing the UES. This area was analyzed using the Micro Analyzer software program.

2.4. Statistical analysis

Means plus the standard deviation (S.D.) were calculated and analyzed by ANOVA followed by a post-hoc Bonferroni or *t*-test. A *p*-value of <0.05 was considered statistically significant.

3. Results

3.1. Food intake

Frame-by-frame analyses of the VFG images clearly revealed the oral structures and food movements during food intake. The mouth opened wide to make room and the tongue moved forward over the incisors to receive the food (Fig. 3A). The initial opening was 34.2±3.4 mm (mean±S.D., $n=15$) and 36.8% larger than the diameter of the given food. The time when the food touched the lower lip and tongue tip was defined as food capture for further measurements. Just after capture, the tongue immediately retracted as the food was introduced into the mouth and the tongue was depressed anteriorly but domed posteriorly to make space for the food (Fig. 3B). The jaw then closed to bite the food, and the tongue slipped its tip below the food and began to dip up the food (Fig. 3C). The weight of one bite of food was 11.5±3.7 g (mean±S.D., $n=15$) and varied among subjects.

The distance of tongue tip movement measured between the position at capture and at the end of the first retraction was analyzed using the Micro Analyzer software program. The distance of tongue tip movement for food intake was obtained as 23.3±6.7 mm (mean±S.D., $n=15$).

Immediately after biting the food, the tongue compressed the food against the hard palate at the incisive papilla with incomplete jaw closure. Thus, the profile of the food was deformed by being shortened anteroposteriorly so that the long axis of the food was vertical to the occlusal plane (tooth row) (Fig. 3D). Thereafter, the food was transported to the occlusal surface of the molar teeth with a second rapid retraction of the tongue during jaw opening; the movement was as if the food had rotated so that the long axis of the food particle was parallel to the row of teeth (Fig. 3E). This entire process was designated stage I transport, as these characteristics of food intake and stage I transport were observed in all subjects. The duration of this process, i.e. the time elapsed from the initial ingestion (maximum opening) to the first tooth-food-tooth contact of molar teeth, was obtained as 1.91±0.31 s (mean±S.D., $n=15$) and was not significantly different among the subjects (Fig. 4).

3.2. Mastication

The jaw movements, which were reconstructed after frame-by-frame analysis, showed a regular trajectory during mastication before the first swallow, in which the closing (CL), occlusal (OC), and opening (OP) phases were clearly identified (Fig. 2A). Mean phase durations in the chewing cycle are shown in Table 1. Each duration in the three phases was stable across the recordings.

In the chewing cycles, the tongue often moved rhythmically in a regular pattern along with the jaw. The tongue kept food in the postcanine area during the CL phase. Food reduction then occurred after tooth-food-tooth contact until minimum gape during the CL and OC phases. The tongue tip began to move forward and contacted the region of the incisive papilla in the late CL phase. The contact area of the tongue with the hard palate then enlarged distally, so that the food was squeezed distally toward the molars. The tongue moved backward during the OP phase and a chewing cycle ended.

The triturated food was transported from the oral cavity to the oropharynx during mastication along with the ongoing chewing (i.e., stage II transport). Stage II transport was not a one-time event. Once a part of the food was ready for transport, it was propelled into the oropharynx by the tongue, so that the tongue tip first contacted the region of the incisive papilla and then aggregated the particles of food from the incisal area of the hard palate during the late CL phase. The posterior part of the tongue dorsum descended during the OC phase, and the tongue dorsum was flattened against the occlusal plane. The tongue pushed upward and distally against the hard palate during the early OP phase, squeezing the food back into the oropharynx. The above mentioned process was repeated until the bolus was accumulated in the oropharynx, and a swallow followed, clearing the food from the oral cavity and pharynx.

3.3. Swallows

An example of the mandibular movement trajectory during a complete feeding sequence is shown in Fig. 1A. A complete feeding sequence normally involved one or two swallows,

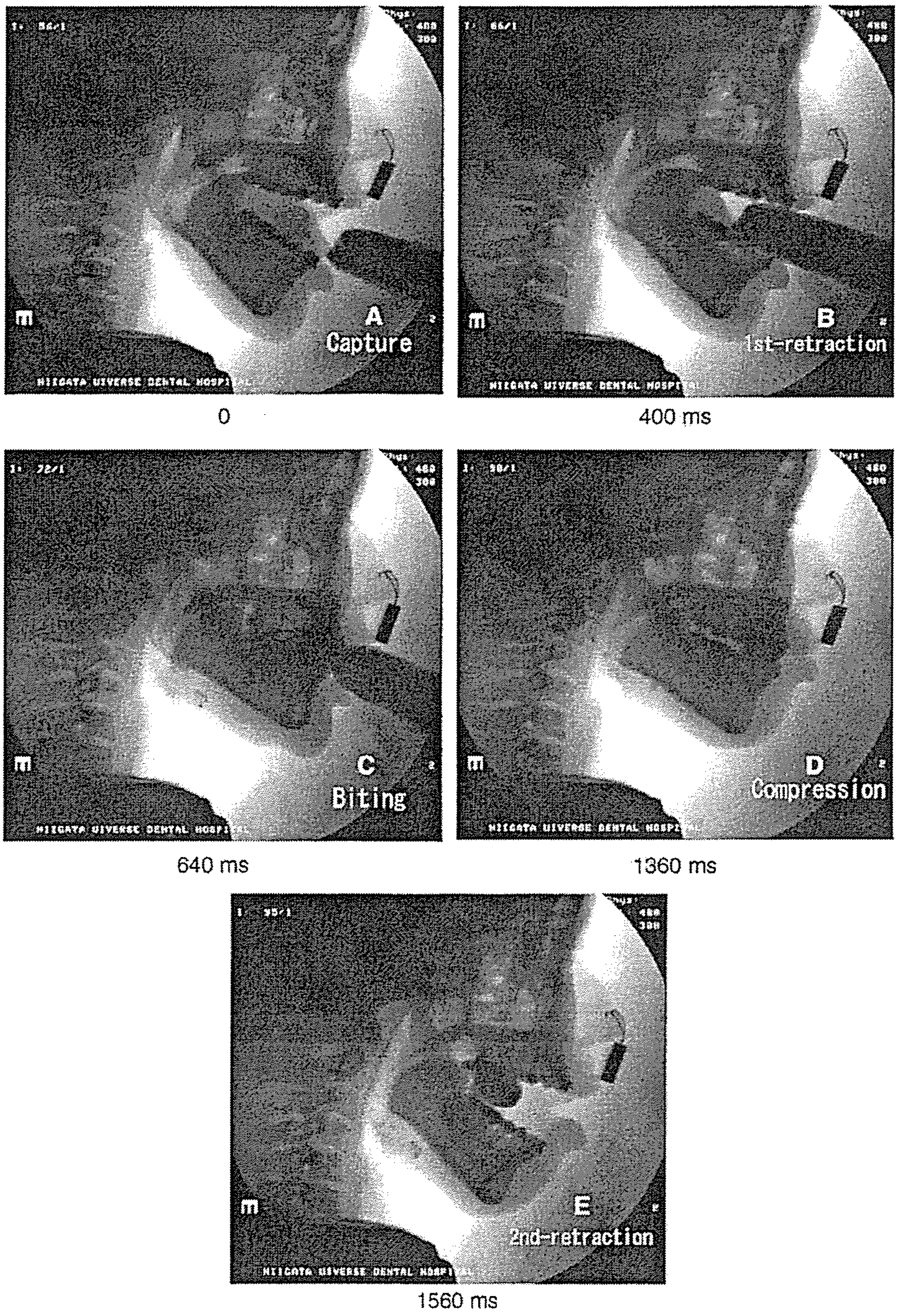

Fig. 3. Tongue movements during food intake as shown by VFG images. (A) The mouth opened wide to make room for the food, and the tongue moved forward over the incisors until it touched the lower lip to receive the food. (B) The tongue introduced the food into the mouth by its retraction. (C) Biting of the food. (D) Just after biting, the tongue compressed the food against the hard palate. (E) The food was transported to the occlusal surface of the molar teeth with a second retraction of the tongue.

preceded and succeeded by chewing cycles (interposed swallows), and ended with an isolated swallow (terminal swallow) to clear the food from the oral cavity and pharynx. This was the case for all subjects, and second interposed swallows were observed in 40% of the trials.

An interposed swallowing cycle was associated with the preceding and succeeding chewing cycles (Fig. 2A). In this case, the swallow-related events of the interposed swallowing cycle began almost exclusively during the OC phase and ended during the OP phase. As shown in Table 1, the duration

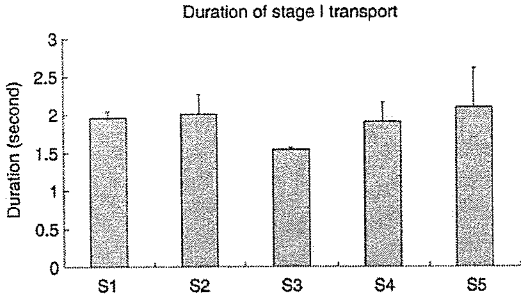

Fig. 4. The duration of stage I transport, (ANOVA); means and S.D. for a total of 15 first-bite records. Data was obtained from five subjects. Difference was analyzed using ANOVA and Bonferroni test. Significance level: $p<0.05$. Total elapsed time during stage I transport is defined starting with the maximum gape and ending with the first teeth-food-teeth contact of molar teeth. This period was not significantly different between the subjects.

of the CL phase of the interposed swallowing cycles (0.25±0.07 s) was similar to that of the chewing cycles (0.22±0.02 s). However, the duration of the OC and OP phases in the interposed swallowing cycles (0.39±0.15 and 0.60±0.09 s, respectively) was significantly longer than that of the OC and OP phases in the chewing cycles (0.17±0.03 and 0.24±0.02 s, respectively) ($p<0.001$). Accordingly, the total duration of the interposed swallowing cycles (1.23±0.09 s) was much longer than that of the chewing cycles (0.63±0.06 s, $p<0.001$).

Similar tongue movements during stage II transport were seen during the interposed swallow, i.e. the tongue squeezed the bolus with the palate toward the oropharynx through the fauces. At the beginning of interposed swallows, the tongue tip rose from the depressed position contacting with the hard palate at the incisal area while aggregating the triturated bolus on its dorsum. The contact area of the tongue with the hard palate enlarged distally, so that the aggregated food was transported backwards to be added to the bolus at the pharynx, which had been transported by stage II transport. The bolus went into the esophagus after nasopharyngeal closure and then laryngeal closure began. Thereafter, the food bolus passed the fauces to end the oral stage. After the food bolus passed through the upper esophageal region, nasopharyngeal closure and then laryngeal closure ended when the jaw opened slowly (Fig. 2A).

A terminal swallow was preceded by characteristic mandibular movements known as preswallowing cycles (Fig. 2B). These cycles were characterized by a decrease in the maximum gape followed by limited irregular mandibular movements. The preswallowing cycles began after maximum opening of regular chewing or interposed swallowing cycles, and they ended just before the onset of the terminal swallowing cycle. During preswallowing cycles, the tongue moved in a way that aggregated the residual food in the mouth in preparation for swallowing. The terminal swallow cycle as well as preswallowing cycles were often incomplete, irregular, and had a low-amplitude of jaw movement, as evaluated from the mandibular movements. Therefore, they could not be divided into three phases, as was the case for the chewing and interposed swallowing cycles (Fig. 2B).

Table 1
Comparisons among the phase duration of jaw movement trajectories in the chewing and interposed cycles

	Chewing cycle	Interposed swallowing cycle	*P*
CL phase	0.22±0.02	0.25±0.07	$P=0.281$
OC phase	0.17±0.03	0.39±0.15	$P<0.001$
OP phase	0.24±0.02	0.60±0.09	$P<0.001$
Total cycle	0.63±0.06	1.23±0.09	$P<0.001$

Values are mean±S.D.
Individual differences were tested using a *t*-test.
Significance level: $p<0.05$.

Table 2
Duration of the oral stage of swallowing in the interposed and terminal swallows

	Interposed swallow	Terminal swallow	*P*
Duration of oral stage	0.38±0.05	0.94±0.47	$P<0.05$

Values are mean±S.D.
Difference was analyzed using a *t*-test.
Significance level: $p<0.05$.

Examples of the oral stage of interposed and terminal swallows are shown in Fig. 2A and B, respectively. The oral stage of the interposed swallow started at the end of the CL phase and ended during the OC phase. On the other hand, the oral stage of the terminal swallow started during the preswallowing cycles and continued until midway through the terminal swallowing cycle. Consequently, the duration of the oral stage in the terminal swallow (0.94±0.47 s) was significantly longer than that in the interposed swallows (0.38±0.05 s, $p<0.05$) (Table 2).

Examples of the swallow-related events, nasopharyngeal closure, laryngeal closure, and UES opening of interposed and terminal swallows are shown in Fig. 2A and B. As shown in Table 3, the durations of both nasopharyngeal and laryngeal closure tended to be longer in the interposed swallows than in the terminal swallows (0.61±0.02 and 0.61±0.03 s, respectively, vs. 0.54±0.08 and 0.53±0.07 s, respectively). However, the duration of UES opening in the interposed swallows (0.35±0.03 s) was significantly longer than that in the terminal swallows (0.22±0.03 s, $p<0.001$).

In this study, the estimated volume of bolus that passed the UES in each swallow was irregular. The area of swallowed bolus in the interposed swallow (569±49 mm^2) was significantly larger than that in the terminal swallow (130±70 mm^2, $p<0.001$).

Table 3
Duration of the swallow-related events in the interposed and terminal swallows

	Interposed swallow	Terminal swallow	*P*
Nasopharyngeal closure	0.61±0.02	0.54±0.08	$P=0.097$
Laryngeal closure	0.61±0.03	0.53±0.07	$P=0.056$
UES opening	0.35±0.03	0.22±0.03	$P<0.001$

Values are mean±S.D.
Individual differences were analyzed using a *t*-test.
Significance level: $p<0.05$.

4. Discussion

The complete feeding sequence in humans has previously been studied using various soft and hard foods, e.g., chicken spread, bananas, hard cookies and peanuts [9], and carrots [13]. However, there appear to be great differences in the preferences and intake frequencies among individuals for these test foods. The purpose of the present study was to examine intra-oral events associated with the management of food during the natural complete feeding sequence. Therefore, we sought a test food of which it was easy for subjects to take one natural bite. Since steamed rice is a staple food in Japan, and Imai et al. [20] recommended it as a test food for the evaluation of masticatory and swallowing functions, we employed it as the test food in this study. Steamed rice also has the advantage of being easy to mix with barium powder for the VFG contrast medium and can be served as a lump without the use of either a spoon or a straw.

Since the VFG required neither head restriction nor any special apparatus attached to the body, we could qualitatively observe natural tongue and jaw movements during food intake. The present study showed that preparatory forward movement of the tongue to receive the food occurred during food intake and that the tongue movement was followed by retraction of the tongue (23.3±6.7 mm) to introduce the food into the mouth. Such tongue manipulation has not been reported previously. We therefore sought to investigate the role of this tongue retraction. There may be two parameters involved in making space for food during food intake into the mouth, i.e., the jaw gape and tongue retraction. Since the coefficient of variation was much smaller in the jaw gape (9.9%) than in the tongue movement (28.8%), it would be reasonable to consider that the food volume could be measured by the distance of tongue retraction. Consequently, we conclude that individual oral stereognosis by tongue manipulations when receiving food and introducing it into the mouth plays an important role in recognizing and evaluating the size of one bite of food.

After biting, one bite of food was immediately placed in the region of the incisive papilla and was slightly compressed by the tongue. Since the test food needed to be processed by dentition, it was transported to the posterior part of the oral cavity (stage I transport). During the compression process, we observed changes in food dimension, movement of the tongue tip, and a close association with the tongue and hard palate. This suggests that the intra-oral compression of food plays a role in the recognition of food texture. In fact, using artificial foods (agar and gelatin gels), Arai and Yamada [12] reported that the process of slight food compression with the tongue and hard palate may be the first step toward texture recognition. A large number of investigators have studied the effects of intra-oral sensory input on the activities of tongue muscles [21–24]. Yokota et al. [21] observed responses of the genioglossal and styloglossal motor units when tactile stimulation was applied to the anterior part of the tongue dorsum. Similarly, Iida et al. [23] observed inhibitory and excitatory responses elicited in the genioglossal and styloglossal muscles, respectively, by stimulating the incisive papilla. These responses elicited in the extrinsic tongue muscles may play a role in the recognition process, in which the tongue tip moves upwards and backwards against the anterior hard palate to evaluate the food texture. The hard palate was found to be one of the most sensitive areas to tactile stimulation [22,24]. The results of this study, therefore, suggest that an important process, i.e., texture recognition, acts on natural food under freely eating conditions.

The duration of stage I transport was measured as 1.91± 0.31 s. However, it was reported to be 280 ms by Hiiemae and Palmer [9]. Why was such a large difference observed? In their study, the subjects were asked to open their mouths to accept 8 g of food, and the food was deposited on the depressed anterior tongue by an examiner directly. On the other hand, the food was taken by the subjects freely in this study. As discussed above, a texture recognition process may precede stage I transport. The present study was able to, therefore, present the novel finding that stage I transport is closely bound to the recognition process when humans take natural food freely.

Interestingly, all subjects ate an amount of food that was more than one swallow volume even though they were instructed to take a bite that would be appropriate for eating sushi. This result is similar to that described by Hiiemae et al. [14] in that a complete feeding sequence involved more than one swallow event after taking a single natural bite of hard food. As described by Ertekin and Aydogdu [25], after ingesting 20 ml of water, normal subjects tended to divide the liquid between two or more swallows; they called this 'piecemeal deglutition.' On the other hand, patients with neurogenic dysphagia were obliged to divide a bolus of less than 20 ml of water into two or more successive swallows. In the present study, regardless of the volume of food in a single natural bite (11.5±3.7 g), two or three swallows were required during a complete feeding sequence. From the VFG images, it was evident that after one interposed swallow, some of the food still remained in the oral cavity, requiring at least one further swallow to clear the residual from the mouth. Since this was the case for all subjects without exception, it could be concluded that humans might need at least two swallows, even with one bite of food, when ingesting food freely. To explain this matter more clearly, however, it will be necessary to take data from additional subjects into consideration.

The present study showed that normal rhythmic chewing cycles immediately precede and succeed an interposed swallowing cycle; i.e. an interposed swallowing cycle is inserted in between chewing cycles. Moreover, swallow-related events in interposed swallowing cycles begin almost exclusively during the occlusal phase and end during the opening phase. In this study, the interposed swallowing cycles had a 0.6 s longer total cycle duration than the chewing cycles due to prolongation of the occlusal and opening phases. This difference in duration was equivalent to the mean duration of nasopharyngeal (0.61± 0.22 s) and laryngeal closure (0.61±0.03 s). Therefore, the interposed swallowing cycle can be interpreted simply as insertion of the swallowing reflex into the occlusal and opening phases of the chewing cycles. These findings were identical to those described by Palmer et al. [6,15] and Hiiemae et al. [14] for humans, and Uchida et al. [26], Meng et al. [10] and Naganuma et al. [11] for animals.

A terminal swallow occurs after characteristic mandibular movements termed preswallowing cycles [27,28] or clearance [14]. Hiiemae et al. [14] reported that regardless of whether such periods were long, short, or absent, they were correlated with the nature of the food, its wettability in saliva, and intraoral 'food management strategies.' In this study, preswallowing cycles were confirmed from VFG frames as long periods in which the residual food was aggregated within the mouth.

Dantas et al. [18] reported that the duration time of the oral stage of swallowing was unaffected by bolus volume. However, the present study showed that the duration time was longer for smaller bolus volumes. This difference may be due to the experimental conditions, in which Dantas et al. studied the duration with command swallow while we studied it with natural swallow. In general, the oral stage of swallowing is thought to be a voluntary movement [29,30] and highly variable in duration depending upon the kind of food, taste, and, for humans, consciousness [25,31]. In the current study, therefore, we could yield the new finding that the oral stage of swallowing is variable in duration depending upon the food volume.

Acknowledgements

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Dysphagia

Influences of Thermal and Gustatory Characteristics on Sensory and Motor Aspects of Swallowing

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Abstract. Two sets of experiments were conducted to examine the effects of two sensory modalities, temperature and taste, of foods on perceptual and motor aspects of swallowing in 20 young, healthy subjects (10 subjects for each experiment). A tasteless and odorless thickening agent was the basic testing material. The first experiment compared the swallowing of foods at four temperatures ranging from 5°C to 50°C. Food at 50°C was more acceptable for swallowing than at 5°C, 20°C, or 35°C. The suprahyoid muscles were less active during swallowing food at 50°C compared with swallowing food at the other three temperatures. The second experiment compared foods with the five basic taste qualities (sweetness, saltiness, sourness, bitterness, and umami) with a tasteless food (dissolved in distilled water) to examine the influence of gustatory sensation. The sweet and tasteless foods were somewhat more acceptable for swallowing than the sour and bitter foods. However, none of the foods differentially altered the motor parameters of swallowing. Interactive influences of temperature and gustatory sensations of foods on swallowing are discussed.

Key words: Swallowing — Temperature — Taste — Sensory evaluation — Motor activity — Deglutition — Deglutition disorders.

During swallowing, boluses stimulate sensory receptors of the oral, pharyngeal, laryngeal, and esophageal regions [1,2]. Initial studies sought to determine effective stimuli and reflexogenetic areas for swallowing in humans [3] and experimental animals [4]. Results indicated that mechanical stimulation of several sites effectively elicited swallowing: the soft palate, faucial pillar, posterior wall of the pharynx, pharyngeal surface of the epiglottis, and pharyngoesophageal junction. Fluids, including water, applied to the extreme posterior part of the tongue also effectively elicited swallowing [4]. More recent studies examined response characteristics of the receptors specifically responsible for swallowing [5–9]. The receptor on the epiglottis of the larynx appears to be a characteristic receptor for eliciting reflex swallowing because water applied to the epiglottis is one of the most effective stimuli for the reflex [4,5,8,9]. These studies suggest that the majority of sensory receptors, including water-sensitive receptors that serve as swallowing initiators, are highly responsive to mechanical stimuli. Responses of medullary neurons receiving signals from sensory receptors are likely to support this suggestion [10].

Therapeutic techniques are needed to facilitate swallowing in dysphagic patients [11–15]. Stimulation of a limited oral area, the anterior faucial pillars, with "multiple" sensory modalities (e.g., mechanical, thermal, and gustatory sensations) enhances the elicitation of reflex swallowing in dysphagic patients [11,14,15]. Similar responses have also been shown in experimental animals [10,16], suggesting that gustatory stimuli applied to the reflexogenetic areas contribute to elicitation of swallowing.

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While previous studies have focused on swallowing elicitation, facilitation, and sensory mechanisms, only a few investigations have examined changes in perceptual and motor processes corresponding to swallowing foods. The present study was designed to answer the following questions: (1) Do the thermal and/or gustatory characteristics of foods affect perceptual processes (e.g., the degree of subjective difficulty) of swallowing? (2) Do the thermal and/or gustatory characteristics of foods affect the motor behavior of swallowing-related muscles? Two sets of experiments were used in the present study to explore these questions.

General Materials and Methods

Subjects

Twenty young (mean age = 22.4 years old) and healthy subjects participated in the experiments. None of the subjects had jaw or oral functional abnormalities. The 20 subjects were divided into two groups for Experiment I (Exp. I) and Experiment II (Exp. II). Both groups consisted of 10 subjects (5 males and 5 females). Before the experiments, the aims and methods of the experiments were explained to the subjects individually, and informed consent was obtained from them.

Test Foods

Since food taste affects thresholds of swallow elicitation [9,12,14,15,17], a tasteless and odorless thickening agent (Mousse-up®, Nisshin Science Clinical Foods, Yokohama, Japan), developed especially for dysphagic patients, was adopted as the basic material for the experiments. The preparation of test foods was as follows: (1) 8 g of thickening agent was dissolved in 100 ml of distilled water (DW), (2) the dissolved agents were mixed up to be creamy, and (3) 8 g of the dissolved agents were placed into needleless plastic syringes. The hardness of each test food sample was measured at room temperature (25°C) using a texturometer (Yamaden Inc., RE-3305S).

Recordings

Electromyograms (EMGs) were recorded with two sets of bipolar surface electrodes. The electrodes were placed on the skin above the masseter and suprahyoid (SH) muscles at the habitual working side of each subject. The EMG signals were amplified and filtered (below 30 Hz and above 3 kHz), and the suprahyoid EMG was integrated as well. Laryngeal movement associated with swallowing was recorded using a device developed by the authors [18]. The start and end stimulus delivery times were recorded using a footswitch with a battery. Data collected with regard to EMGs, laryngeal movement, and times of food delivery were stored on magnetic tapes for later analyses.

Sensory Evaluation

Subjective difficulty of swallowing (SDS) was evaluated using a psychometric method. In the evaluation, each subject was required to focus on the sensation in the throat where the swallowed bolus passed over. In each session, he/she first remembered the degree of SDS of the first standard stimulus (SS). Three trials using the SS were conducted in subjects in both Exp. I (Table 1) and Exp. II (Table 2). Then, subjects estimated relative changes in SDS by comparing the comparative stimuli (CS) with the SS. A set of sheets was given to each subject to record the SDS rating using a five-stage scale ("much easier" = −2.0, "easier" = −1.0, "equal" = 0.0, "more difficult" = +1.0, and "much more difficult" = +2.0). In-between ratings such as −1.5 and + 0.5 were used optionally. Medians were calculated by scores of SDS for the SS and CS.

Table 1 Order of stimulus presentation of foods of four temperatures

Trial	Temperature (°C)	
1st	35	SS[a]
2nd	5	CS[b]
3rd	20	CS
4th	50	CS
5th	5	CS
6th	35	SS
7th	50	CS
8th	20	CS
9th	50	CS
10th	35	SS
11th	20	CS
12th	5	CS
13th	35	SS

The order of stimulus presentation was the same in all of the three sessions conducted. [a]standard stimulus, [b]comparative stimuli. See text for details.

Procedures

After setting up for EMG and laryngeal movement recordings, each subject was instructed to sit on a chair comfortably in an air-conditioned (25°C) and shielded room. The instructions for the subjects in every trial were as follows: (1) open the mouth slightly and hold the position for a while, (2) accept 8 g of the food poured from a syringe to the oral floor, (3) close the mouth and dip up the food with the tongue quickly, (4) swallow it without chewing, (5) rinse the mouth with tea if necessary, and (6) report sensory evaluation of SDS. There was about a 2-min interval between trials. One session consisted of 13 trials in Exp. I (Table 1) and 14 trials in Exp. II (Table 2). Three sessions were conducted with each subject in both experiments. There was an interval of more than one week between sessions.

Swallowing Movement

Since masseter EMG activity was very weak in almost all of the trials, only the SH EMG activity was analyzed. As described in our previous report [18], three strong activities were observed in the SH EMG before and during swallowing: Opening, Burst 1, and Burst 2 (Fig. 1; Fig. 2 of [18]). The subjects were asked to swallow test foods immediately after being placed in the mouth and without chewing (see Procedures section above). We assumed that the first burst of the SH muscles (Opening in Fig. 1) would be associated with opening the mouth and that the second burst (Burst 1) would correspond to bolus