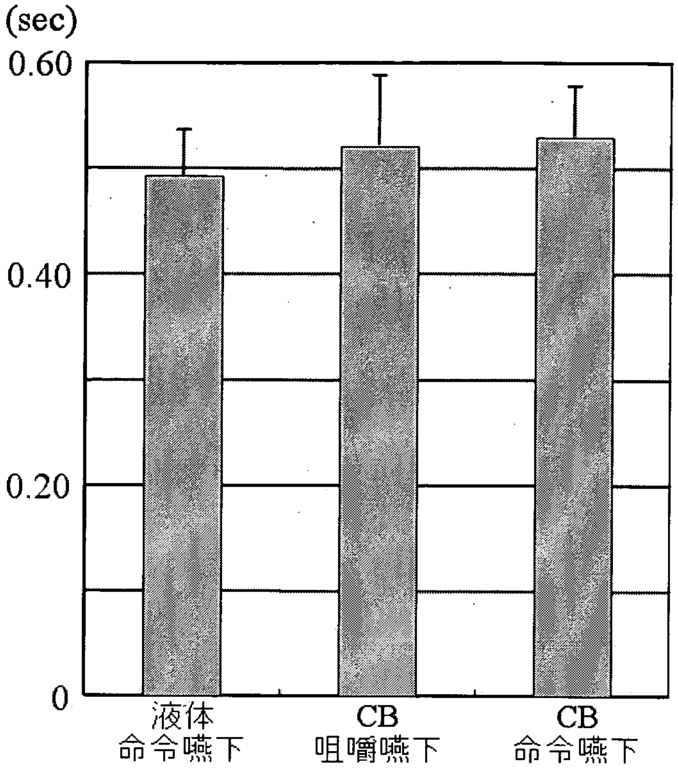
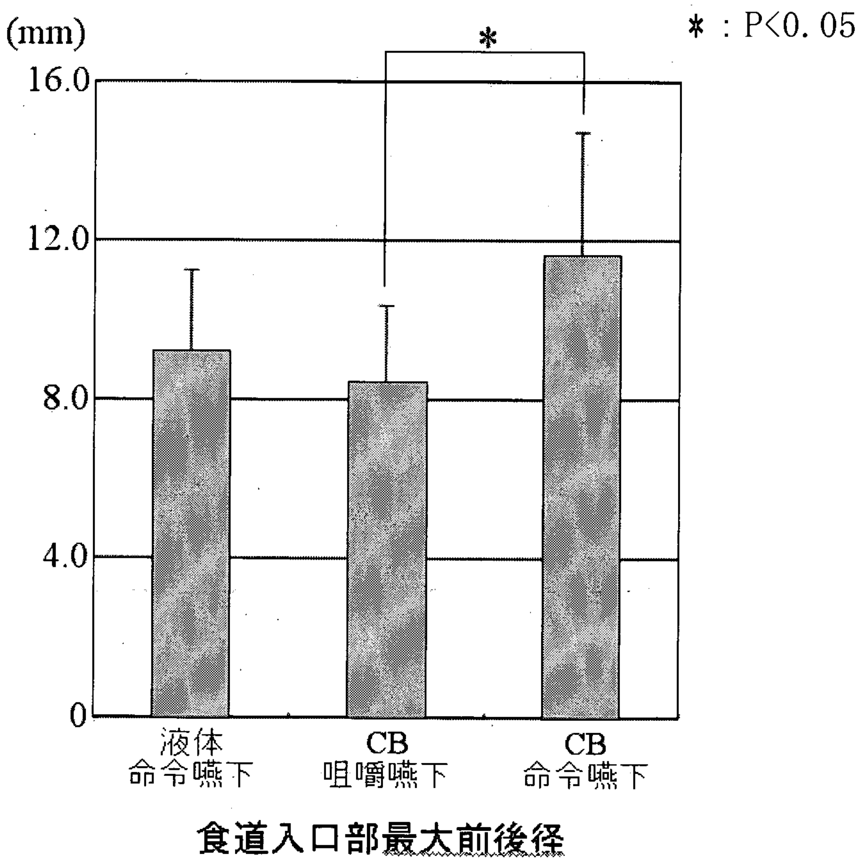


舌骨挙上時間



食道入口部最大前後径

図2　舌骨挙上時間と食道入口部最大前後径

厚生労働科学研究費補助金

分担研究報告書

食品による窒息の現状把握と原因分析

CT画像の三次元造形による中咽頭部の形状評価

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研究要旨：

食品による窒息のヒト側のリスク要因として、咽頭・喉頭部のエアウェイを歯顎顔面用コーンビームX線CT装置および三次元造形システムを用いて、立体構築後に評価することにより、エアウェイの最狭部の位置や同部位の断面、最狭部位の三次元形態の特徴などについての視覚的に容易に評価可能であった。同システムで幼児と成人、老人を比較したところ窒息のリスク部位である中咽頭部の長さが幼児は成人に比較してかなり短く、老人は喉頭下垂のために長くなっているエアウェイの状態が視覚的に直接比較可能であり、窒息の原因となっている食品の形態とヒト側のリスクとしてのエアウェイの形態を関連させて検討するのに有用であることがわかった。

A 目的

食品による窒息事故のヒト側のリスク要因として、食品が停留しやすいと推察される中咽頭・下咽頭の形態をエアウェイとして直接的な模型として造形して、形態の特徴のみならず最狭部の位置や断面積を知ることは窒息の原因分析を行う上で重要である。しかし、窒息事故の頻度が高い小児期と高齢期は、咽頭腔の形態の加齢変化

が大きい時期にあたる。そこで、窒息の原因を分析するヒト側の要因として、この時期の咽頭腔の形状を客観的に評価する方法と加齢による形態変化の分析方法を考案することを目的に本研究を行った。

B 方法

医科用X線 CT 装置(GE 横河メディカル HiSpeed9XI、以下 CT)および歯顎顔面用コーンビームX線 CT 装置(日立メディコ製 CB MercuRay、以下 CBCT)の2つの装置にて撮影を行った。撮影条件は臨床にて一般的に使用される条件を用い、画像は三次元造形システム（米国Z社製三次元造形機 Z510 、Materialise 社製三次元画像処理ソフトウエア mimics , Magics) にて咽頭・喉頭部の立体構築を行った1)。構築された3D 画像からエアウェイの描出精度及び4歳の幼児、20 歳代の成人、70 歳代の高齢者についてエアウェイの三次元造形模型を制作し、立体的な咽頭腔の形態評価についてその可能性を検討した。

C 結果と考察

エアウェイの描出精度では、軟組織である咽頭部については CT と比較して CBCT においてその表出精度が優れており、立体構築後の形態評価に適していた（研究を継続して第 14 回日本摂食・嚥下リハビリテーション学会発表予定)。

また、CT や CBCT は通常、骨や軟組織などの実質の形態学的特徴を評価するものであるが、虚像である咽頭・喉頭部のエアウェイを実像として立体構築し、三次元造形システムにより模型を製作した。窒息の場であるエアウェイの実態模型からは側貌断面の薄さと前額断面の幅の広さ、および咽頭腔のエアウェイの最狭部の位置、同部位の断面、最狭部位の三次元形態の特徴、中咽頭前壁の細かな凹凸程度などについての視覚的に容易に評価可能であった（図１)。

幼児と成人、高齢者を中咽頭、下咽頭に分けて比較した(図２，３，４)。窒息のリスク部位である中咽頭の長さは、ともに幼児はかなり短く幅も狭く、咽頭前壁の凹凸も複雑で強い傾向が伺えた。これに対して高齢者の中咽頭は成人に比較して加齢による喉頭下垂のために長くなっており2)、幼児と高齢者では窒息の原因となる食品の物性や形などが異なることも推察された3)。

しかしながら、咽頭腔の最狭部の位置や断面の形態特徴などについては

未だ明らかにできていない。今後、このシステムを使って窒息のヒト側の要因であるエアウェイの特徴について、窒息の好発年齢である小児期と高齢期について解析を行う予定である。

D 参考文献

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E 研究発表

1．論文発表

なし

2．学会発表

なし

F 知的財産権の取得状況

1．特許取得

なし

2．実用新案登録

なし

別表参照

図 1　エアウェイの描出

図 2　エアウェイの年齢比較（側面）

図 3　エアウェイの年齢比較（喉頭蓋側）

図 4　エアウェイの年齢比較（咽頭後壁側）

別表

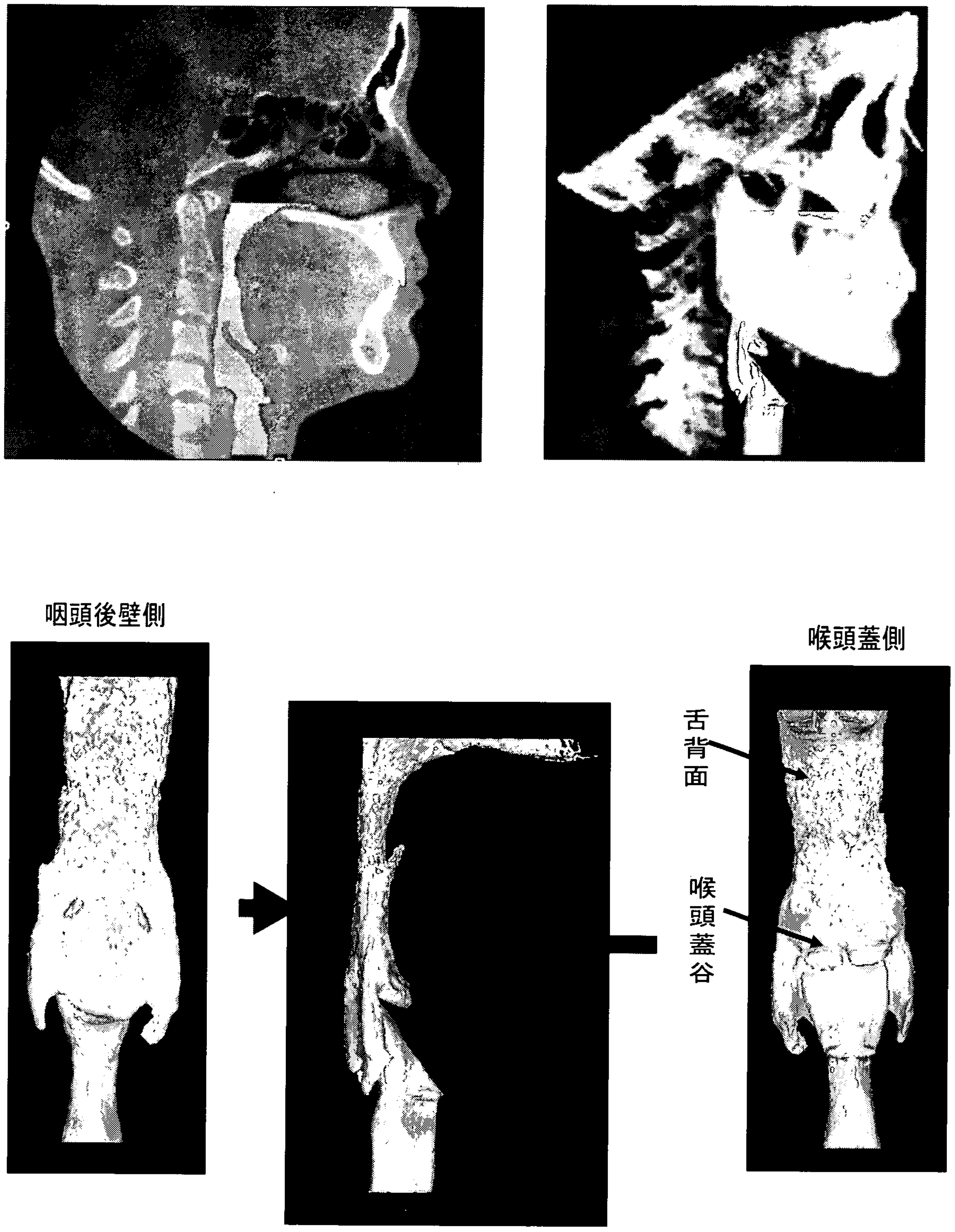

図１　エアウェイの描出

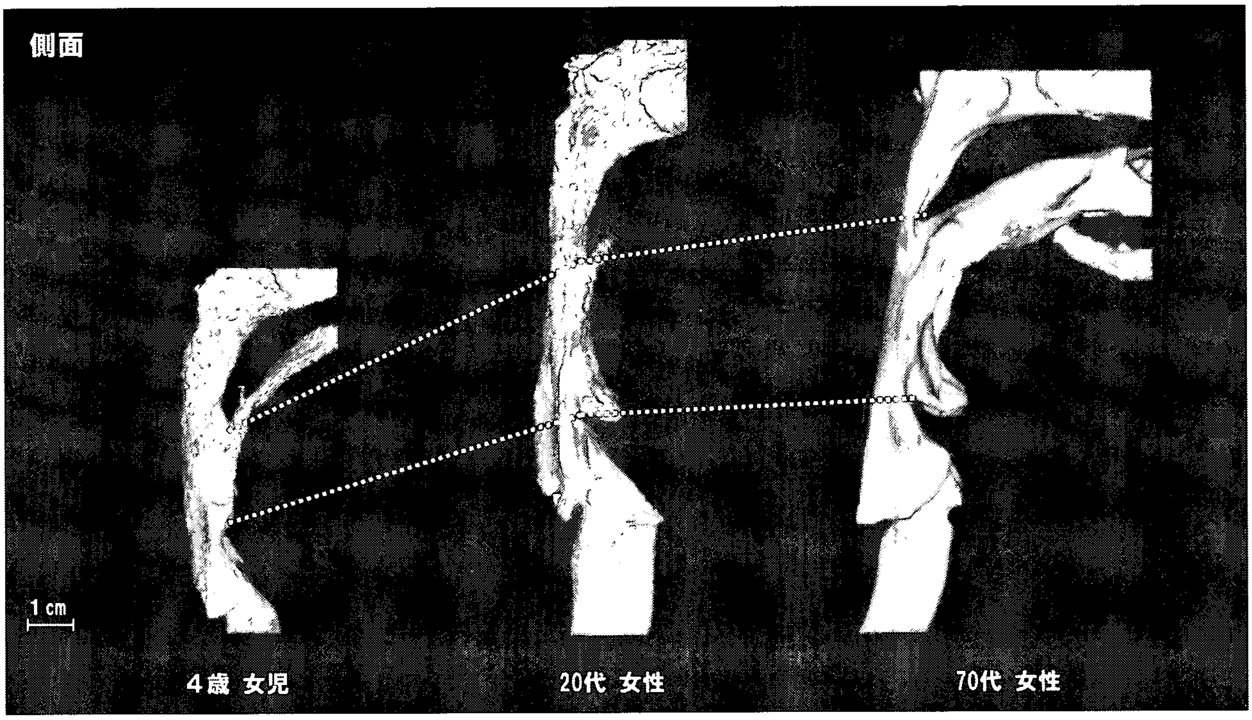

図2　エアウェイの年齢比較（側面）

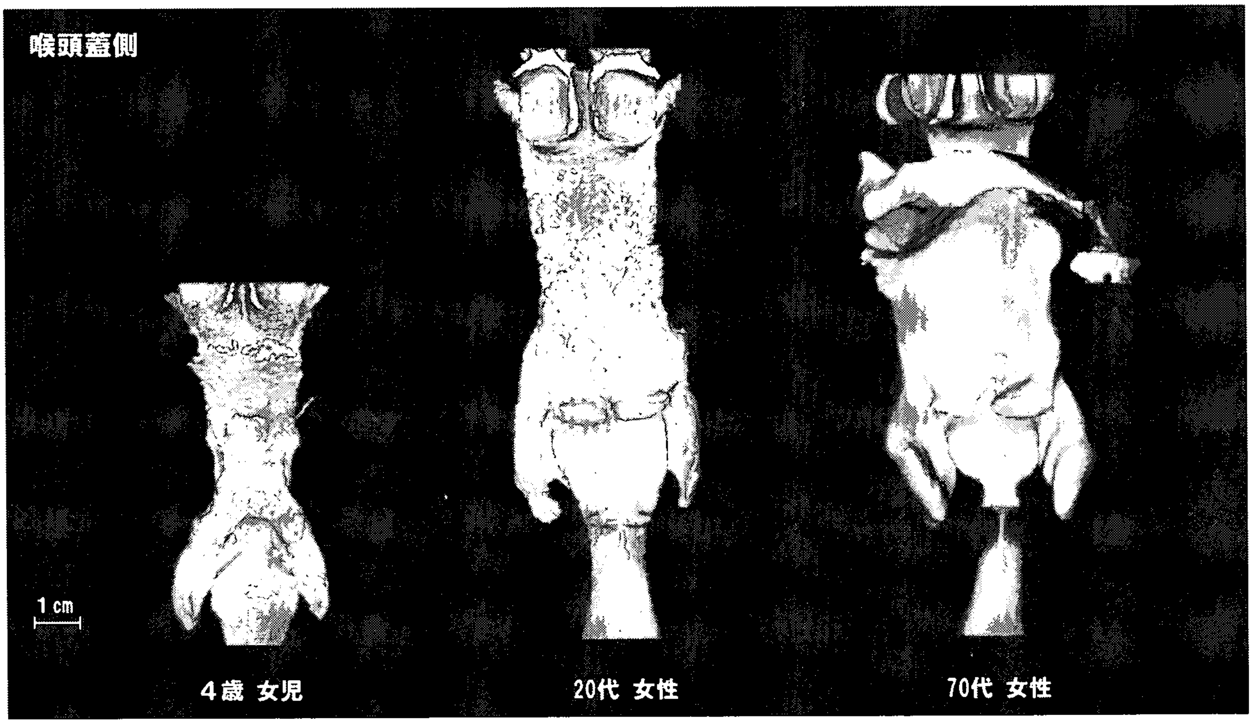

図3　エアウェイの年齢比較（喉頭蓋側）

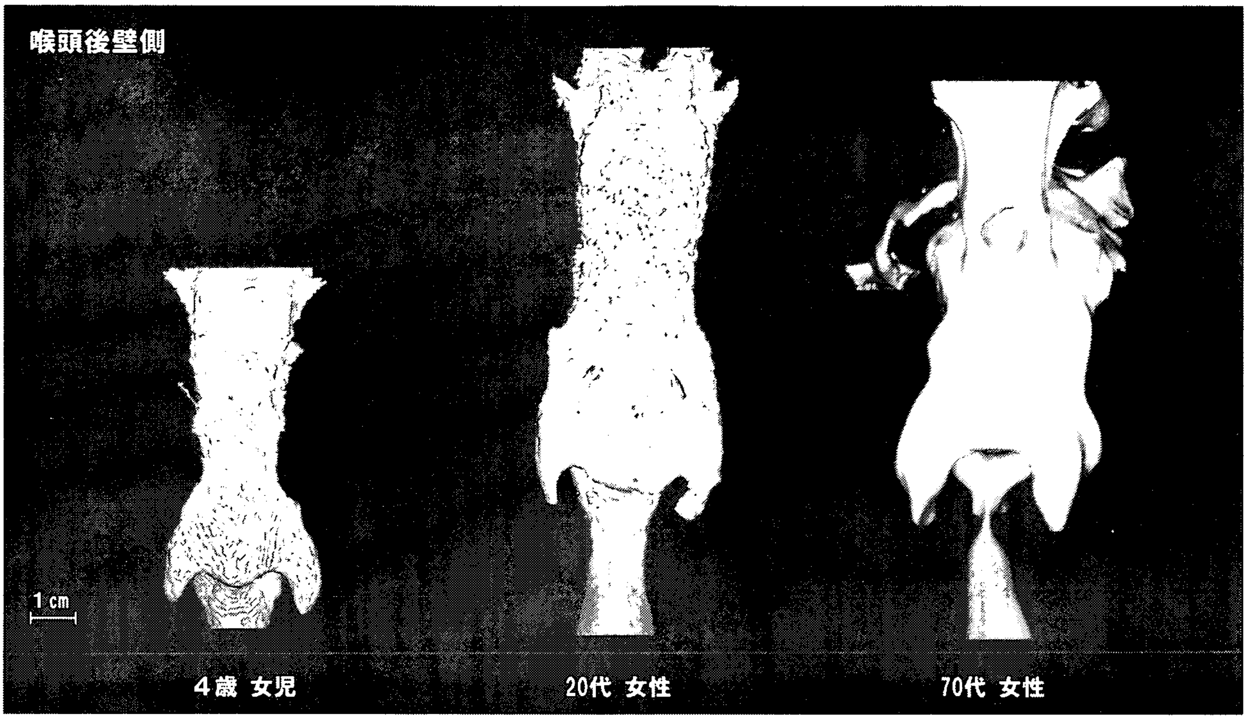

図４　エアウェイの年齢比較（喉頭後壁側）

研究成果の刊行に関する一覧表

論文発表

1. Saitoh E, Shibata S, Matsuo K, Baba M, Fujii W, Palmer JB : Chewing and food consistency: effects on bolus transport and swallow initiation. Dysphagia, 22 (2) :100-107, 2007.
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Dysphagia 22:100–107 (2007)
DOI: 10.1007/s00455-006-9060-5

Dysphagia

Chewing and Food Consistency: Effects on Bolus Transport and Swallow Initiation

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Abstract. Preswallow bolus formation usually occurs in the mouth for liquids and in the oropharynx for solid foods. We examined the effect of chewing on the relationship between bolus transport and swallow initiation. Fifteen healthy subjects were imaged with lateral projection videofluorography while eating liquids, solid foods, and a mixture of liquid and solid foods in upright and facedown postures. Videotapes were reviewed to measure the location of the leading edge of the barium at swallow initiation. Chewing and initial consistency each altered the relationship between food transport and swallow initiation. In particular, when chewing liquid (or consuming foods with both liquid and solid phases), a portion of the food commonly reached the hypopharynx well before swallow onset. This transport to the hypopharynx was highly dependent on gravity, but transport to the valleculae for chewed solid food was active, depending primarily on tongue-palate contact. Chewing appeared to reduce the effectiveness of the posterior tongue-palate seal, allowing oral contents to spill into the pharynx. Consuming two-phase foods with both solid and liquid phases may increase the risk of aspiration in dysphagic individuals with impaired airway protective reflexes.

Key words: Deglutition — Chewing — Mouth — Pharynx — Fluoroscopy — Viscosity — Deglutition disorders.

Swallowing is traditionally divided into four stages: oral preparatory, oral propulsive, pharyngeal, and esophageal. Inherent in the four-stage model is the concept that these stages are sequential, and that bolus propulsion to the pharynx normally does not occur until the time of swallow onset [1]. This model was based on observation of liquid swallows [2, 3] but does not adequately reflect the events in eating solid food, especially bolus aggregation in the pharyx before swallowing.

Palmer et al. [4, 5] have examined how normal subjects eat solid food. These studies have shown that chewed solid food may be transported to the pharynx (stage II transport) up to 10 s before swallow onset. Chewing may continue while food accumulates in the oropharynx. With liquid swallows, a part of the bolus may enter the pharynx before swallow onset [6], especially in older subjects [7], but with chewed solid food, a large bolus commonly accumulates in the oropharynx. Indeed, the oropharynx appears to be the normative location for bolus formation when normal subjects eat solid food. Stage II transport is an active process that is dependent on the tongue squeezing the food against the palate and is not dependent on gravity [8]. In comparing the processes of drinking liquids and eating solids, there are two fundamental differences: (1) consistency of the food and (2) the need to chew solid items before swallowing and coordinate the acts of chewing and intraoral food transport with swallowing. A question arises as to whether food transport to the pharynx before swallow onset (stage II transport) is related to the act of chewing or is a function of food consistency. If it is a result of the act of chewing, then

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chewing food before swallowing should produce stage II transport well before swallowing, even for liquids. If it is a result of food consistency, then food transport to the pharynx with liquids should occur at the time of swallow onset, even when subjects chew the liquids before swallowing.

This study was designed to examine the hypothesis that stage II transport and bolus aggregation in the pharynx are related to the act of chewing, and to reexamine whether the mechanism of stage II transport is a result of action of the tongue or a result of gravity.

Materials and Methods

Subjects

Fifteen healthy young adults [nine male and six female, mean age = 30 ± 5.2 (SD) years] participated in this study. Each subject gave oral and written informed consent. The protocol was approved by Institutional Review Board at Fujita Health University, where all recordings were made. All subjects were in excellent health, with no history of major neurologic or morphologic problems related to deglutition and no complaint of dysphagia.

Procedure

Each subject was seated comfortably in a chair (upright posture) and videofluorography (VFG) was performed at 30 frames/s in lateral projection. Each recording covered the interval from the food entering the mouth until the end of the first swallow. A video timer was used to add a time signal to the videotape in 0.01-s increments. Each subject consumed the following foods: liquid barium (LQ), corned beef hash with barium (CB), shortbread cookie with barium (CO), and a two-phase mixture of liquid barium and corned beef hash (MX). For liquid barium, 10 ml of 50% wt/vol liquid barium was placed in the mouth with a syringe, and subjects were instructed to swallow the liquid in their usual manner. We refer to this as the "liquid-no chewing" (LQ-nc) recording. An additional recording was made with instructions to chew the 10 ml of liquid barium and then swallow (LQ-chew). For CB and CO, the 8 g of food was placed in the mouth and subjects were instructed to eat the food in their usual manner. For MX, 4 g of CB was placed in the mouth, and then 5 ml of liquid barium was injected in the mouth with a syringe.

Review of the videotapes showed that with LQ-chew, CB, CO, and MX, the subject always chewed before swallowing. The complete set of recordings in upright posture was then repeated. Next, two additional recordings each were made for LQ-chew, CB, and MX with the subject in facedown posture. This was accomplished by having the subject bend forward from the waist while looking straight down, supporting the upper body by placing both hands on a platform such that the upper body and head were parallel to the ground [8]. The recordings in the upright posture were always completed before those in the facedown posture.

Data Analysis

VFG recordings were reviewed in slow motion. A single recording was defined as the time from a sample of food entering the mouth until the end of the first swallow. The data from three sequences for MX (upright posture), one sequence for LQ-chew (upright posture), and one sequence of CB (facedown posture) were excluded because of technical difficulties with the recordings. The remaining 235 recordings (146 upright, 89 facedown) were included in the analysis.

We used the Process Model paradigm to divide each sequence into intervals. This model was developed for analysis of feeding with solid food and was selected for this study because the traditional system of dividing swallowing into stages is inappropriate for studies of feeding. The Process Model has been validated in several studies [4, 5, 8]. The intervals were defined follows:

(1) Processing: Solid food was chewed and mixed with saliva; liquids may be manipulated in the mouth. This interval begins with entry of the food into the oral cavity and ends when the leading edge of the barium passes under the posterior nasal spine.

(2) Oropharynx aggregation time: Chewed and softened solid food was propelled through the fauces into the pharynx. If food remained in the mouth, chewing continued. This interval begins when the leading edge of the barium passes the posterior nasal spine and ends when it passes the edge of the epiglottis and/or aryepiglottic folds. Oropharynx aggregation time was subdivided into two intervals:

(a) Postfaucial aggregation time (PFAT): Chewed food passed through the fauces and collected on the pharyngeal surface of the tongue. It ends when the leading edge of the barium reaches the level of the inferior border of the mandible.

(b) Vallecular aggregation time (VAT): Chewed food collected in the valleculae. VAT ends when the leading edge of the barium passes the edge of the epiglottis, entering the hypopharynx.

(3) Hypopharynx transit time (HTT): Barium passed through the hypopharynx. Starting with the end of VAT, this interval ends when the trailing edge of the barium reaches the upper esophageal sphincter.

To measure the effects of food consistency on swallow initiation, we recorded the position of the leading edge of the barium at the time of swallow onset. The position was defined as follows (Fig. 1): oral cavity (from the lips to the posterior nasal spine), upper oropharynx (from the posterior nasal spine to the level of the lower border of the mandible), valleculae (from the lower border of the mandible to the edge of the epiglottis), or hypopharynx (from the edge of the epiglottis to the upper esophageal sphincter).

Differences were tested with the nonparametric Friedman analysis of variance (ANOVA) and Wilcoxon's matched-pairs signed-ranks test (with Bonferroni correction) for *post hoc* testing. Timing measurements included the duration of each interval and the interval from the start of HTT until swallow onset (defined as the moment when the hyoid bone begins its rapid superior and anterior motion). Timing data were transformed logarithmically because variances were not homogeneous in that variance increased with higher mean values. Logarithmic transformation provided appropriately distributed data. Differences were analyzed with mixed-model ANOVA that included differences among subjects and differences among food conditions (i.e., LQ-nc, LQ-chew, CB, CO, and MX). For LQ-chew, CB, and MX, the effects of body posture (upright vs. facedown) on timing measures were tested with paired-sample *t* tests. The critical value for rejecting the null

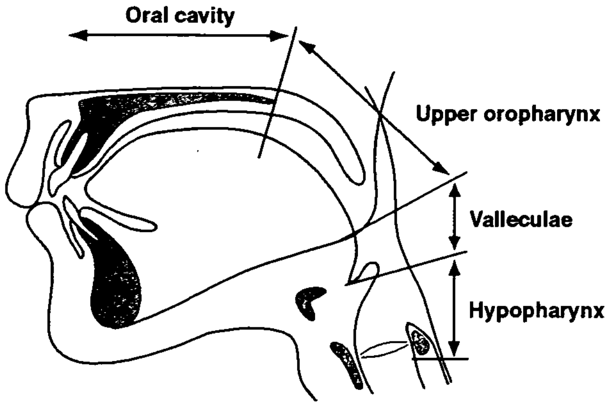


Fig. 1. The location of the leading edge of the barium is defined by four regions: (1) oral cavity, (2) upper oropharynx (behind the fauces but above the inferior border of mandible), (3) valleculae (below the inferior border of the mandible but above the hypopharynx), and (4) hypopharynx. Swallow onset is defined as the moment when the hyoid bone began its rapid elevation preceding swallowing.

hypothesis was $p < 0.05$. Statistical procedures were performed with SPSS v11.0 (SPSS Inc., Chicago, IL).

Results

Location of the Leading Edge of Barium at Swallow Onset

Upright Posture

The data for the location of the leading edge of barium swallow onset are given in Table 1 and shown in Figure 2. The leading edge of liquid barium was significantly deeper in the pharynx at swallow onset with chewing (LQ-chew) than without (LQ-nc) ($p < 0.001$). The leading edge of the barium was in the oral cavity or upper oropharynx at swallow onset in 69% of liquid swallows without chewing (LQ-nc) but in only 30% with chewing (LQ-chew). Conversely, liquid was in the hypopharynx at swallow onset in 33% with chewing but in only 3% without chewing. With corned beef hash (CB) and cookie (CO), the leading edge of the barium was usually in the valleculae at swallow onset (60% and 70% of swallows, respectively), and seldom entered the hypopharynx before swallow onset. The leading edge of the barium was significantly lower in the foodway at swallow onset with mixture (MX) than with LQ-chew ($p = 0.001$), LQ-nc ($p < 0.001$) or the other foods ($p < 0.001$). With MX, the leading edge of the barium was in the valleculae or hypopharynx at swallow onset for every sequence recorded (37% in the valleculae and 63% in the hypopharynx). Careful review of the videotapes revealed that it was the liquid phase of the mixed food that first entered the valleculae and hypopharynx.

Facedown Posture

The location of the leading edge of barium at swallow onset was next examined in facedown posture for LQ-chew, CB, and MX. The leading edge was in the upper oropharynx or valleculae at swallow onset for 73% of swallows with liquid (with chewing), 100% with CB, and 93% with MX. The leading edge was in the hypopharynx at swallow onset for 10% with liquid (with chewing), none with CB, and 3% with MX. The location of the leading edge of barium at swallow onset varied significantly among food conditions (Friedman test, $p = 0.05$) but paired comparisons among food conditions were not significant (Wilcoxon test, $p > 0.15$).

Comparing findings in the upright and facedown postures revealed statistically significant effects: The location of the leading edge of the barium at swallow onset was significantly deeper in the pharynx in the upright than in the facedown posture for LQ-chew ($p = 0.01$) and for MX ($p < 0.001$). With CB, however, posture had no significant effect on the location of the leading edge of the barium at swallow onset ($p = 0.82$).

Timing of Food Transport

The timing of food transport was analyzed by measuring the duration of each interval in the sequence (Processing, PFAT, VAT, and HTT) (Table 2, Fig. 3). Log-transformed data were analyzed with mixed-model ANOVA (Tables 3 and 4, Fig. 4). The data presented in the text, figures, and legends are raw, untransformed data for ease of understanding.

Upright Posture

In the upright posture, the duration of Processing varied significantly among food conditions and subjects ($p < 0.001$ for each). It was significantly shorter for LQ-nc (1.5 [0.82–5.5] s, median [interquartile] s), LQ-chew (3.9 [1.4–7.0] s), and MX (2.6 [1.5–5.3] s) than it was for CB (6.9 [4.8–10.0] s) and CO (12.8 [7.5–16.7] s). Thus, foods with liquid phases had shorter Processing durations than solid or semisolid foods.

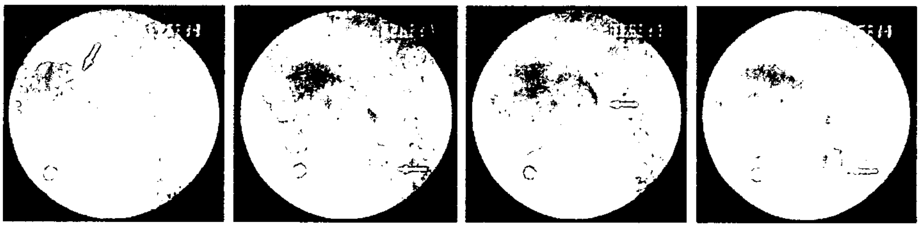
Duration of postfaucial aggregation time (PFAT) varied significantly among food conditions ($p < 0.001$) but not among subjects ($p = 0.21$). It was significantly shorter for LQ-nc (0.23 [0.10–0.40] s) than for any other food condition. PFAT duration

Table 1. The location of the leading edge of the barium at swallow onset

	Liquid no chewing	Liquid with chewing	Corned beef hash	Cookie	Mixture
Upright posture					
Total	29 (100.0)	30 (100.0)	30 (100.0)	30 (100.0)	27 (100.0)
Oral cavity	9 (31.0)	3 (10.0)	3 (10.0)	1 (3.3)	0 (0.0)
Upper oropharynx	11 (37.9)	6 (20.0)	9 (30.0)	5 (16.7)	0 (0.0)
Valleculae	8 (27.6)	11 (36.7)	18 (60.0)	21 (70.0)	10 (37.0)
Hypopharynx	1 (3.4)	10 (33.3)	0 (0.0)	3 (10.0)	17 (63.0)
Facedown posture					
Total	–	30 (100.0)	29 (100.0)	–	30 (100.0)
Oral cavity	–	5 (16.7)	0 (0.0)	–	1 (3.3)
Upper oropharynx	–	11 (36.7)	13 (44.8)	–	9 (30.0)
Valleculae	–	11 (36.7)	16 (55.2)	–	19 (63.3)
Hypopharynx	–	3 (10.0)	0 (0.0)	–	1 (3.3)

Values are *N* (%).

a) Upright position



LQ-nc (Oral cavity) **LQ-chew (Hypopharynx)** **CB (Valleculae)** **MX (Hypopharynx)**

b) Facedown position

LQ-chew (Valleculae) **CB (Valleculae)** **MX (Valleculae)**

Fig. 2. Example of VFG images at swallow onset in various recordings. Upper row, subject upright; lower row, subject facedown. For consistency, the image for the facedown position is rotated 90° in this illustration. Arrow shows the leading edge of the barium. With subject upright, for LQ, the leading edge was in the oral cavity at swallow onset without chewing but in the hypopharynx with chewing. With MX, the leading edge entered the hypopharynx at swallow onset. With subject facedown, for all foods, the leading edge was in the valleculae at swallow onset and not in the hypopharynx. LQ-nc = liquid without chewing, LQ-chew = liquid with chewing, CB = corned beef hash, MX = a mixture of liquid and corned beef hash.

Table 2. The median and (interquartile intervals) (s) in recordings for each food condition

	Liquid no chewing	Liquid with chewing	Corned beef hash	Cookie	Mixture
Upright					
Processing	1.54 (0.82–5.49)	3.86 (1.38–7.03)	6.93 (4.80–10.0)	12.8 (7.45–16.7)	2.57 (1.53–5.31)
PFAT	0.23 (0.10–0.40)	0.46 (0.13–1.42)	1.86 (0.46–4.89)	2.09 (0.79–4.90)	0.67 (0.13–1.23)
VAT	0.06 (0.04–0.11)	0.10 (0.04–1.84)	0.72 (0.07–1.72)	1.07 (0.13–3.08)	0.80 (0.30–1.57)
HTT	0.46 (0.40–0.53)	0.52 (0.45–0.65)	0.48 (0.40–0.54)	0.47 (0.43–0.60)	0.86 (0.47–1.93)
Facedown					
Processing	–	3.29 (1.42–5.17)	7.27 (3.93–10.6)	–	3.99 (2.43–6.61)
PFAT	–	0.47 (0.12–1.32)	3.57 (1.42–5.91)	–	1.16 (0.26–3.08)
VAT	–	0.07 (0.03–1.08)	0.10 (0.07–2.65)	–	0.59 (0.03–2.29)
HTT	–	0.51 (0.49–0.58)	0.44 (0.39–0.50)	–	0.50 (0.47–0.54)

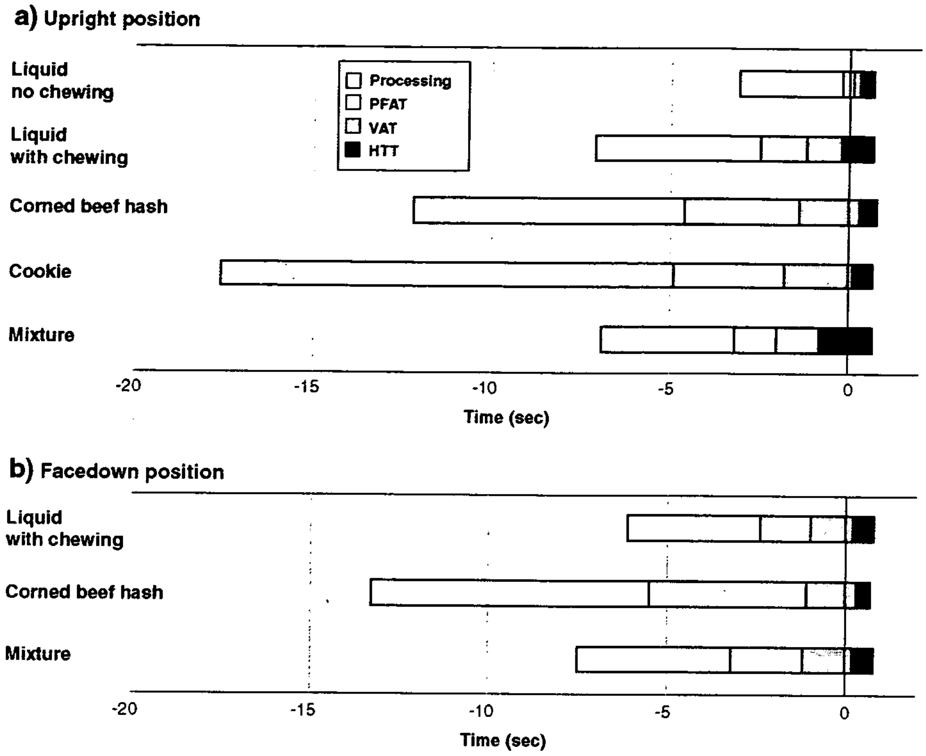


Fig. 3. Timelines showing the mean duration for each interval of the feeding sequences for each food with subject (a) upright and (b) facedown. Time 0 is swallow onset. (a) In the upright position, with chewing CB or CO, total duration was longer than for the other foods because of the initial consistency, and swallow onset was during VAT. With chewing LQ and MX, swallow onset occurred during HTT. (b) In the facedown position, for all foods, swallow onset was during VAT for all foods. PFAT = postfaucial aggregation time, VAT = vallecular aggregation time; HTT = hypopharyngeal transit time.

Table 3. Mixed-model ANOVA for the each interval in the sequence with logarithmic transformation

	Processing		PFAT		VAT		HTT	
	F value	*p* value	*F* value	*p* value	*F* value	*p* value	*F* value	*p* value
Upright posture								
Food	32.24	< ***0.001***	10.05	< ***0.001***	5.39	***0.001***	9.10	< ***0.001***
Subject	3.46	< ***0.001***	1.45	0.162	1.77	0.068	2.13	***0.024***
Food * Subject	0.79	0.815	1.92	***0.005***	2.14	***0.001***	2.19	***0.001***
Facedown posture								
Food	12.35	< ***0.001***	13.50	< ***0.001***	0.64	0.537	6.13	***0.006***
Subject	2.21	***0.036***	4.57	< ***0.001***	2.51	***0.019***	1.49	0.177
Food * Subject	1.91	***0.027***	1.52	0.104	1.48	0.119	0.91	0.600

Table 4. Paired *t* test: the difference in each interval comparing the upright and facedown postures

	Processing		PFAT		VAT		HTT	
	t value	*p* value	*t* value	*p* value	*t* value	*p* value	*t* value	*p* value
Liquid with chewing	1.13	0.267	−0.17	0.865	−0.21	0.838	2.11	***0.044***
Corned beef hash	−0.13	0.899	−1.65	0.110	0.94	0.356	1.50	0.144
Mixture	−1.11	0.276	−1.90	0.069	−0.31	0.762	3.56	***0.001***

was significantly shorter for LQ-chew (0.46 [0.13–1.4] s) and MX (0.67 [0.13–1.23] s) than for CB (1.9 [0.46–4.9] s) and CO (2.1 [0.79–4.9] s). As with Processing, PFAT duration was shorter for foods with liquid phases, but in this case liquid without chewing had the shortest duration.

Valleculae aggregation time (VAT) duration differed significantly among food conditions ($p < 0.004$) but not among subjects ($p = 0.08$). It was significantly shorter for LQ-nc (0.06 [0.04–0.11] s) than for LQ-chew (0.10 [0.04–1.8] s) or for the other foods (CB, 0.72 [0.07–1.7] s; CO, 1.1 [0.13–3.1] s; MX

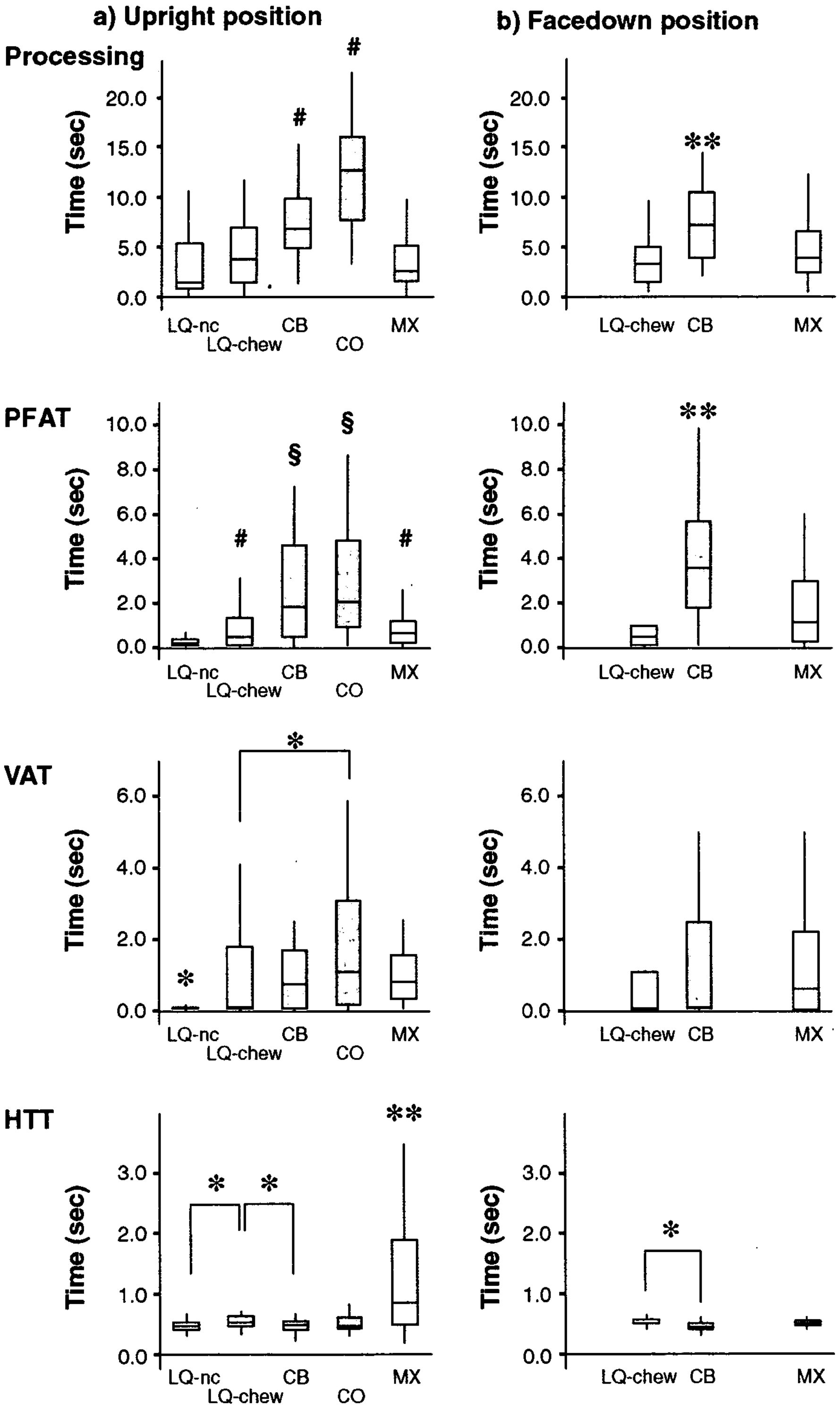


Fig. 4. The box-whisker plots for each food with subject onset (**a**) upright and (**b**) facedown. The asterisks (* and **) indicate a statistically significant difference ($p < 0.05$ and $p < 0.001$, respectively). When appearing over a single column, the asterisk(s) indicates that the column is significantly different from the other columns. When appearing over a bracket between two columns, it indicates that those two columns are significantly different from one another. The symbols (#, §) over two columns indicates that the columns are not significantly different from each other but are different ($p < 0.05$) from the other columns. (**a**) With chewing MX or LQ, HTT was longer than the others (except for LQ-chew vs. CO, $p = 0.46$). (**b**) Processing and PFAT durations were longer with CB than with LQ-chew or MX. HTT was slightly but significantly longer for LQ-chew than for CB. HTT was significantly longer in the upright than in the facedown position for LQ-chew ($p = 0.04$) and MX ($p = 0.01$), but not for CB ($p = 0.14$). Abbreviations are as in Figures 2 and 3.

0.80 [0.30–1.6] s). VAT duration was also significantly shorter for LQ-chew than for CO. As with Processing and PFAT, VAT duration was shortest for liquid without chewing.

There were significant differences in hypopharyngeal transit time (HTT) duration among foods ($p < 0.001$) and among subjects ($p = 0.02$). HTT duration was significantly shorter for LQ-nc (0.46 [0.40–0.53] s) and CB (0.48 [0.40–0.54] s) than for LQ-chew (0.52 [0.45–0.65] s), and was longer for MX (0.86 [0.47–1.9] s) than for the other foods. This pattern is quite different from the other intervals.

HTT was generally longest for chewing with foods that included a liquid phase (i.e., LQ-chew and MX).

Facedown Posture

In the facedown posture, the duration of Processing varied significantly among foods ($p < 0.001$) and among subjects ($p = 0.03$). It was significantly longer for CB (7.3 [3.9–10.6] s) than for LQ-chew (3.3 [1.4–5.2] s) or MX (4.0 [2.4–6.6] s). Processing duration did not differ significantly between upright and facedown postures ($p > 0.26$).

Duration of PFAT varied significantly among foods ($p < 0.001$) and among subjects ($p < 0.001$). It was significantly longer for CB (3.6 [1.4–5.9] s) than for LQ-chew (0.47 [0.12–.3] s) or MX (1.2 [0.26–3.1] s). There were significant differences among subjects ($p < 0.001$) but not between LQ-chew and MX. Comparing upright and facedown postures, there were no significant differences ($p > 0.06$).

VAT duration did not differ significantly among foods ($p = 0.65$), but there were significant differences among subjects ($p = 0.03$). VAT duration did not differ significantly between upright and facedown postures for any food ($p > 0.36$).

There were significant differences in HTT duration among foods ($p = 0.01$) but not among subjects ($p = 0.19$). It was significantly longer for LQ-chew (0.51 [0.49–0.58] s) than for CB (0.44 [0.39–0.50] s; $p = 0.006$). HTT duration was significantly longer in the upright than in the facedown position for LQ-chew ($p = 0.04$) and MX ($p = 0.01$) but not for CB ($p = 0.14$).

Timing of Swallow Onset

We measured the interval from start of HTT (the moment that the leading edge of the barium entered the hypopharynx) until the time of swallow onset (defined as the start of rapid upward and forward motion of the hyoid bone). In upright position, this interval varied significantly among food conditions ($p < 0.001$) and among subjects ($p = 0.02$). It was significantly longer for MX than for any other food ($p < 0.001$); there were no significant differences among the other foods. On average, barium entered the hypopharynx before swallow onset for MX (−0.30 [−1.4 to + 0.17] s) but after swallow onset with LQ-nc (0.10 [0.07–0.33] s), LQ-chew (0.07 [−0.02 to + 0.20] s), CB (0.27 [0.14–0.35] s), and CO (0.17 [0.13–0.27] s). The interval from start of HTT until swallow onset was sometimes quite long. In one case (with MX), HTT started 4.6 s before swallow onset.

In facedown posture, the interval from start of HTT to swallow onset did not vary significantly among food conditions ($p = 0.65$) or among subjects ($p = 0.76$). On average, HTT started after swallow onset for all three foods (LQ-chew, 0.13 [0.10–0.28] s; CB, 0.20 [0.12–0.30] s; MX, 0.19 [0.10–0.27] s).

Comparing the two postures, the interval from start of HTT to swallow onset was significantly longer when subjects were facedown than upright for LQ-chew ($p = 0.012$) and MX ($p < 0.003$), but posture had no significant effect for CB.

Discussion

This study was the first to examine the effects of chewing on swallowing liquids. When our subjects swallowed after chewing, the leading edge usually reached the oropharynx (liquids or solids) or the hypopharynx (mixed consistency) before swallow onset. These findings are consistent with earlier studies that showed that liquids (without chewing) were generally held in the oral cavity until swallow onset, while chewed solid food was propelled into the pharynx significantly before swallow onset [1, 4, 7–9]. The instruction to chew liquids was unusual and may have produced an idiosyncratic response. However, mixed consistencies are consumed commonly as part of a regular diet, so the observed findings more likely reflected real-life behaviors.

The early movement of liquid barium from the oral cavity to the pharynx during chewing was consistent with loss of posterior tongue-soft palate contact. As shown recently [9], the soft palate rises and falls cyclically during chewing, moving upward as the jaw opens. This periodic elevation of the soft palate pulls it away from the tongue, allowing food to move from the oral cavity into the pharynx. In this study movement of liquid into the hypopharynx before swallowing was dramatically reduced by placing subjects in the facedown position, suggesting that transport to the hypopharynx was largely caused by gravity. Elevation of the soft palate during chewing provided a route for bolus movement from the oral cavity, but the flow was powered by gravity. An alternative explanation for this phenomenon is that the act of chewing inhibited swallow initiation, permitting food to move further down into the pharynx before a swallow response was elicited. Several studies reported that stimulation of the chewing area of the fronto-orbital cortex and the lingual nerve delayed or inhibited the swallowing reflex in sheep [10, 11].

During feeding, chewed solid food is propelled to the pharynx by an active process driven by action of the tongue pressing against the palate [4, 5, 8, 12].

Our results support this model in that the leading edge of the barium for chewed solid food (CB or CO) was usually in the oropharynx (either in the upper oropharynx or valleculae) at the time of swallow onset and was not altered by facedown position. Chewed solid food only rarely entered the hypopharynx before swallow onset. We infer that the chewed solid food was more viscous than liquid and formed a cohesive bolus, so it was less likely to move into the hypopharynx under the influence of gravity [13].

Our findings imply that standards for evaluating the timing of food transport and swallowing must recognize the influence of food consistency and chewing behavior. The concept of "delayed pharyngeal response" (failure to rapidly trigger a pharyngeal swallow response when barium reaches the faucial pillars) is commonly cited as evidence that swallowing is abnormal [14]. Both age and food consistency can have effects on timing measures, as shown previously [4, 5, 7]. The present study shows that the act of chewing may also influence the timing of food transport and swallow initiation. We further suggest that clinicians consider including two-phase foods, which combine liquid and solid textures, in the evaluation of individuals with dysphagia, because the pattern of food transport and swallowing is quite different from that seen with other foods. The early arrival of barium in the hypopharynx may put some individuals at risk for aspiration when they consume two-phase foods, because the larynx may be open while a significant amount of liquid is in the hypopharynx. This is especially important for individuals with impaired swallowing and reduced airway protective mechanisms.

Acknowledgments. This study was supported in part by a Health Sciences Research Grant, Comprehensive Research on Aging and Health (H-11-Choju-035) from the Ministry of Health, Labour and Welfare, Japan (to ES) and by USPHS Award R01 DC02123 from the National Institute on Deafness and Other Communication Disorders (to JBP).

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特集　リハビリテーション医療

摂食・嚥下障害のリハビリテーション

才藤栄一*

キーワード　摂食・嚥下障害　リハビリテーション　嚥下訓練　プロセスモデル

Ⅰ．摂食・嚥下障害の意味

リハビリテーション（以下，リハビリ）では，嚥下（飲み込み；swallow）の問題に限局せず，広く，食物を口まで運び，口に取り入れ，咀嚼し，飲み込むという食事行動の問題（eating problem），すなわち，摂食・嚥下障害を扱う1)．

摂食・嚥下障害は医療場面にとどまらない．患者の多くは，摂食・嚥下障害を抱えたまま施設や自宅で生活することになるからである．したがって，対応には多様な医療者のチームワークが必要となる．

1995年，基本的知識を獲得し，チームワークを発展させる学際的学会として日本摂食・嚥下リハビリテーション学会が創設された．現在，会員数5,000名の同学会は，年1回の学術大会のほか，年3号の雑誌発行，各地での講習会開催など活発な活動を行っている．

Ⅱ．摂食・嚥下の基礎知識

嚥下とは口腔内の食塊（bolus）を胃まで運搬する運動を意味する．嚥下運動は古典的には3期または4期モデルで説明される．4期モデルでは，嚥下を口腔準備期，口腔送り込み期，咽頭期，食道期に分ける．3期モデルでは準備期が省略される．これらのモデルは，嚥下造影検査の標準的方法であった命令嚥下（command swallow）と呼ばれる，「口腔に保持した液体を合図で飲み込む」嚥下時に観察される運動から生まれた．前述したようにリハビリでは，より広くとらえるため，何をどんなふうに食べるかを決定・行動する「食物を口に入れるまでの時期」である先行期を加え，5期に区分する2)．

一方，近年，障害という観点からでなく，生理学的にも「食べること（咀嚼嚥下；chew-swallow）」はただ「飲み込むこと」ではないと考えられるようになった．固形物の咀嚼嚥下所見から，プロセスモデル（process model）が生まれた3)．咀嚼嚥下では，咀嚼中につくられた食塊は舌によって能動的に輸送され（Stage II transport），中咽頭（口峡〜喉頭蓋谷）でまとめられることが明らかとなった．さらに，液体を含む場合には，食塊は嚥下反射開始前に中咽頭を超えて下咽頭まで達することも明らかになった4,5)（図1）．

Ⅲ．摂食・嚥下障害の評価

摂食・嚥下障害の原因は，その病態生理から，口腔・咽頭・喉頭・食道に器質的病変を伴う解剖学的問題と神経筋疾患による生理学的問題とに分けられる．高齢社会になった現在，生理学的問題が多く，脳血管障害やパーキンソン病など中枢神経疾患に伴うものがその多くを占めている．脳血管障害では，病態として多発性脳病変による仮性球麻痺，脳幹病変による球麻痺が

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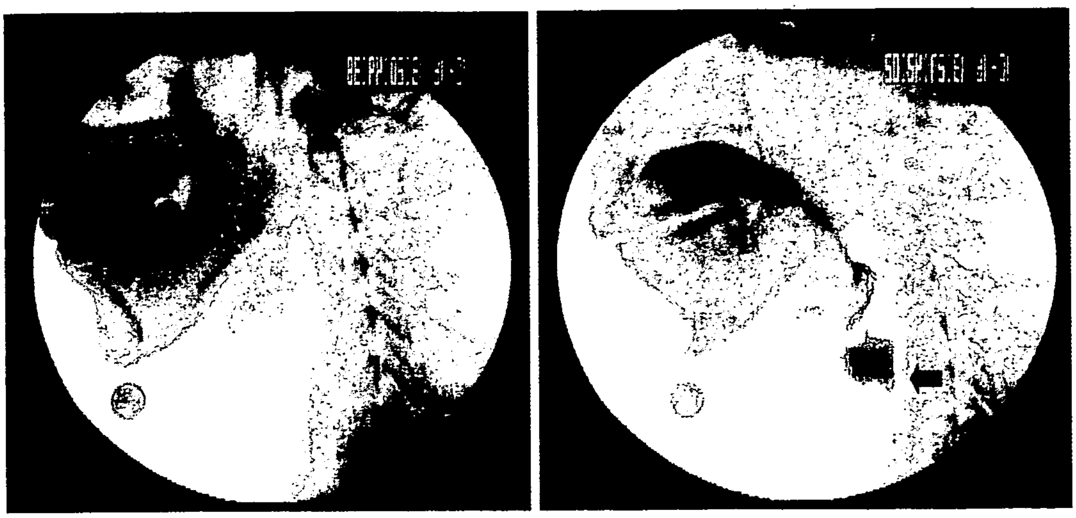
液体の命令嚥下　　混合物の咀嚼嚥下

図1　命令嚥下と咀嚼嚥下における嚥下反射開始直前の食塊位置

31歳，健常女性．舌骨の急速な上方への運動の直前の嚥下造影像．舌骨の急速な上方への運動をもって咽頭期嚥下反射の開始とした場合，液体の命令嚥下では食塊が口腔内にあった．液体・コンビーフの混合物を咀嚼嚥下すると食塊は，嚥下前に下咽頭（梨状窩）まで達した．矢印は食塊先端位置を示す．

（米本恭三監修：最新リハビリテーション医学　第2版，医歯薬出版，東京，2005；122-132より引用）

表1　高齢者に多い摂食・嚥下の問題

- 塩味，苦味の閾値上昇
- 歯牙欠損による咀嚼能力の低下
- 唾液腺の萎縮
- 咽頭期反射の惹起性の低下
- 安静時の喉頭の低位化
- 嚥下—呼吸協調性の低下
- 咳嗽反射の低下
- 薬剤使用による問題
- 気付かれない疾患の存在（脳梗塞など）

（米本恭三監修：最新リハビリテーション医学．第2版，医歯薬出版，東京，2005；122-132より引用）

重要である．加齢の影響は多様であり一様ではないが，高齢者にみられやすい問題を表1に挙げる5)．

主訴，病歴，経過は分かりにくい．神経疾患による摂食・嚥下障害の場合，その訴えは少なく，家族も問題を軽視しがちである．3～5割の誤嚥患者は「ムセのない誤嚥（silent aspiration)」を有している．夜間咳嗽，繰り返す発熱，体重減少，食事嗜好の変化などに気を付ける．

身体所見では，まず，意識状態，呼吸状態に注意する．意識状態が悪い場合，摂食・嚥下機能も低下する．呼吸状態が良好な場合，積極的な訓練に進める場合が多い．特に，咳嗽が十分強くできる例は良い．

口腔状態では，齲歯，歯肉炎，歯石，口腔内残渣，舌苔，唾液の性状，義歯をチェックする．高齢障害者の口腔衛生状態は不良である場合が多い．

下部脳神経（三叉，顔面，舌咽，迷走，舌下神経）の感覚・運動機能を評価する．その際，口腔・咽頭機能の片側性（機能の偏り）の有無に注意する．

嚥下後や食後のゼロゼロした声（gargling voice）は，喉頭侵入（laryngeal penetration；声門上，喉頭内に食物が侵入すること）を示唆する所見として重要である．

規格化された嚥下機能検査としては，反復唾液嚥下テスト(RSST;repetitive saliva swallowing test)5,6)，改訂水飲みテスト（MWST；modified water swallow test)7)，食物テスト（FT；food test)7)などがある．安全性は高く，経管患者

表2　内視鏡検査と造影検査の特徴

内視鏡検査	造影検査
直接的画像	間接的画像（X線画像）
"3次元的"画像	2次元画像
咽頭腔内視野	体内構造物同定可能
口腔運動観察不可能	口腔運動観察可能
嚥下反射時観察不可能*	嚥下反射運動観察可能
視野安定性に問題	視野安定性は良好
食物加工が不要	造影剤付加が必要
被曝なし	被曝あり
ポータブル，ベッドサイド	遮蔽室，患者移動
ファイバーの苦痛，阻害	苦痛なし

*ホワイトアウト：嚥下反射時には咽頭腔の収縮に伴って視野が確保できず，白色画面になる現象．嚥下反射直後の喉頭下降に伴って視野が回復し，喉頭内が観察可能となり，喉頭内侵入や誤嚥の有無を確認できる．両検査の誤嚥判定の一致率は高いが，検出性にはそれぞれの特徴がある．

（米本恭三監修：最新リハビリテーション医学．第2版，医歯薬出版，東京，2005；122–132より引用）

にも使用できる．

経口摂取例では食事場面の観察が必要となる．食物をかき込むような切迫的な摂食，不適切な介助法はしばしばみられる問題である．

臨床所見による誤嚥の診断率は概して高くなく，誤嚥など臨床的に治療必要性が疑われる症例では，嚥下造影検査（VF；videofluorography）あるいは嚥下内視鏡検査（VE；videoendoscopy）を行う．これらの検査では，形態異常の発見，誤嚥や咽頭残留など動的病態の理解を通した重症度判断はもちろん，食物形態，体位・肢位，代償手技などの効果判断など治療戦術に直結する情報を採取できる．日本摂食・嚥下リハビリ学会から嚥下造影検査の標準的手法が発表されている8)．VFと比較したVEの特徴を示す（表2）5)．検査に伴う誤嚥がもたらす危険は十分な注意を払えば大きくない．

Ⅳ．摂食・嚥下障害への対応

目標は，患者にとって安全かつ最良の摂食状態をつくることである．スクリーニング検査や精密検査を組み合わせて評価し，①摂食・嚥下障害の重症度を判定し，②機能帰結を大まかに予測し，③治療環境を考慮に入れて，④各種の対応をしながら，⑤再評価，という手順が取られる．

摂食・嚥下機能，摂食状態，医学的安定性の3つを個別に評価することが合理的な治療方針を考えるうえで基本になる（表3，4）5)．

摂食・嚥下障害への対応は，口腔ケア，訓練，代償手技，経管法，医学的管理からなる．

口腔ケアは嚥下訓練の前提条件となる．介助を要する障害者の口腔衛生はおしなべて不良である9)．専門的な口腔ケアが高齢者の誤嚥性肺炎発生率を低下させることが報告されている10)．口腔ケアの要点は，物理的清掃にある．麻痺や廃用による口腔内残渣や代謝物の自浄不足を補い，口腔内を「活動的な状態」にすることが主目的となる．特に舌背と口蓋に注意を払う．口腔衛生状態の改善と共に食事への意欲改善や口腔過敏の改善が期待できる．

訓練には，間接訓練（indirect therapy）と直接訓練（direct therapy）がある．詳細は省略するが，前者は食物を使わないので安全であるが効果は上がりにくく，後者は食物を用いて効果は上がりやすいが誤嚥の危険を伴う．両者を併用して，安全性と効果の両者を確保するよう努める．一般に自然回復期を過ぎたと思われる慢性期患者でみた場合，大幅な訓練効果を上げることは少ないが，それでも機能レベルで一定の改善をみる11)．また，長期経過例でもそれまで未介入の症例では著明な訓練効果が得られる場合もある．

体位・肢位により嚥下（誤嚥防止，食塊通過）のしやすさが異なることを利用し，より安全な食べ方をつくり出す．一般に，頭部屈曲位（chin tuck または chin down），リクライニング位，そして，咽頭機能の左右差がある場合，頸部患側回旋位，健側側傾位が有効な体位・肢位である．

食物の種類・形態は，嚥下の難易度を変化させる．生理学的特性としては，明確な感覚入力

表3　臨床的重症度分類（主として機能的摂食・嚥下障害を対象とした分類）

分類		定義	解説	対応法	直接訓練*
誤嚥なし	7　正常範囲	臨床的に問題なし	治療の必要なし	必要なし	必要なし
	6　軽度問題	主観的問題を含め何らかの軽度の問題がある．	主訴を含め，臨床的な何らかの原因により摂食・嚥下が困難である．	簡単な訓練，食事の工夫，義歯調整，などを必要とする．	症例によっては施行
	5　口腔問題	誤嚥はないが，主として口腔期障害により摂食に問題がある．	先行期，準備期も含め，口腔期中心に問題があり，脱水や低栄養の危険を有する．	口腔問題の評価に基づき，訓練，食物形態・食事法の工夫，食事中の監視が必要である．	一般医療機関や在宅で施行可能
誤嚥あり	4　機会誤嚥	時々誤嚥する，もしくは咽頭残留が著明で臨床上誤嚥が疑われる．	通常のVFにおいて咽頭残留著明，もしくは，時に誤嚥を認める．また，食事場面で誤嚥が疑われる．	上記の対応法に加え，咽頭問題の評価，咀嚼の影響の検討が必要である．	一般医療機関や在宅で施行
	3　水分誤嚥	水分は誤嚥するが，工夫した食物は誤嚥しない．	水分で誤嚥を認め，誤嚥・咽頭残留防止手段の効果は不十分だが，調整食など食物形態効果を十分認める．	上記の対応法に加え，水分摂取の際に間欠経管栄養法を適応する場合がある．	一般医療機関で施行可能
	2　食物誤嚥	あらゆるものを誤嚥し嚥下できないが，呼吸状態は安定．	水分，半固形，固形食で誤嚥を認め，食物形態効果が不十分である．	経口摂取は不可能で経管栄養が基本となる．	専門医療機関で施行可能**
	1　唾液誤嚥	唾液を含めてすべてを誤嚥し，呼吸状態が不良．あるいは，嚥下反射が全く惹起されず，呼吸状態が不良．	常に唾液も誤嚥していると考えられる状態で，医学的な安定が保てない．	医学的安定を目指した対応法が基本となり，持続的な経管栄養法を要する．	困難

*訓練には，食物を使った直接訓練と食物を使わない間接訓練がある．間接訓練は6以下のどのレベルにも適応があるが，在宅で施行する場合，訓練施行者に適切な指導をすることが必要である．

**慎重に行う必要がある．

（米本恭三監修：最新リハビリテーション医学．第2版，医歯薬出版，東京，2005；122−132より引用）

表4　摂食状態と医学的安定性

摂食状態	5. 経口－調整　無 4. 経口－調整　要 3. 経口＞経管 2. 経口＜経管 1. 経管
医学的安定性	A. 安定 B. 不安定

（米本恭三監修：最新リハビリテーション医学．第2版，医歯薬出版，東京，2005；122−132より引用）

をもたらす食物，すなわち，塩味・辛味のはっきりした，温かい・冷たいという温度のはっきりした食物が有利とされる．物理学的特性（物性）としては，食塊が均一で凝集性が高く，付着性が低く，変形性が大きいものが有利である．凝集性は咽頭内でまとまって散らばらず誤嚥を防ぐ特性である．とろみをつける増粘剤（thickening agent）が多種市販されるようになった．均一でない食物は咀嚼を誘発し，それが前述したStage II transportを生み，嚥下反射前に食塊が咽頭内に進行するので，喉頭閉鎖機能の悪い患者では誤嚥の危険を高めてしまう．そこで，嚥下調整食（modified food）は咀嚼を要しない均一な物性の「丸飲み食」が原則となる．

直接訓練の中核となる段階的摂食訓練では，