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Original Article

Physical properties of pressurized and heat-treated meat gels and their suitability as dysphagia diet based on swallowing dynamics

Ai Tokifuji, RD, M NS,[1] Yasuyuki Matsushima, MD, PhD,[2] Kenji Hachisuka , MD, PhD,[2] Keiko Yoshioka, PhD[3]

[1]Graduate School of Health and Nutritional Sciences, Nakamura Gakuen University, Fukuoka, Japan
[2]Department of Rehabilitation Medicine, University of Occupational and Environmental Health, Kitakyushu, Japan
[3]Department of Nutritional Sciences, Nakamura Gakuen University, Fukuoka, Japan

ABSTRACT
Tokifuji A, Matsushima Y, Hachisuka K, Yoshioka K. Physical properties of pressurized and heat-treated meat gels and their suitability as dysphagia diet based on swallowing dynamics. Jpn J Compr Rehabil Sci 2012; 3:18–25.
Objective: We evaluated the suitability of pressurized and heat-treated meat gels as a dysphagia diet by studying the swallowing dynamics in dysphagic patients.
Methods: Minced pork mixed with water at a ratio of 1:0.5 or 1:1 was pressurized at 400 MPa for 20 min using a food pressure testing machine and steamed to 80ºC. Two types of pressurized and heat-treated (PH) gel samples were prepared: 1:1 PH gel and 1:05 PH gel. Heated patty and heated paste samples were also prepared from minced pork. Textural measurements, sensory evaluation and videofluoroscopic examination of swallowing (VF) were conducted on these samples.
Results: Textural measurements showed that the PH gels were softer compared to the heated patty, and lower in adhesiveness than the heated paste. In the sensory test, PH gels were evaluated to be more elastic and easier to swallow, with no residue remaining in the oral cavity. In VF conducted in dysphagic patients, the numbers of mastication and gulps for the 1:1 PH gel were 14.6 and 3.1, respectively; and the transit time through the oropharynx was 12.33 sec, which was shorter than those for the 1:0.5 PH gel and the heated patty.
Conclusion: The 1:1 PH gel was easy to form a bolus and smooth to swallow. The present results suggest that this gel may be suitable for consumption by dysphagic patients.
Key words: pressurized and heated meat gel, physical property, dysphagia diet, dysphagic patients, videofluoroscopic examination of swallowing

Correspondence: Ai Tokifuji, RD, M NS
Graduate School of Health and Nutritional Sciences, Nakamura Gakuen University, 5−7−1 Befu, Jounan-ku, Fukuoka 814−0198, Japan
E-mail: toki1015@nakamura-u.ac.jp
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Introduction

In Japan, people aged over 65 comprise 22.7% of the total population [1], and many elderly people have difficulty in consuming food due to a decrease in masticatory or swallowing function. Swallowing difficulties affect 30 to 50% of all patients after an acute stroke, and persist in approximately 10% of these patients [2]. Difficulty in eating causes protein and energy malnutrition, which often delays recovery from diseases, and consequently leads to deterioration of the quality of life [3]. This background indicates that there is a need to develop a dietary food that is easy to masticate and swallow by elderly people and dysphagic patients. Some previous studies have examined the relationship between the physical properties of food and masticatory and swallowing functions. For example, Takahashi et al. [4−6] reported the physical properties of meat and chewing movements, and Hatae et al. [7] and Toda et al. [8] reported the preference of the elderly for food textures and methods of cooking meat.

The covalent bonds of protein are not changed by high pressurization, but the non-covalent bonds are changed with deformation of three-dimensional structures. High pressurization changes protein into a state of coagulation or gel, which differs from protein products treated by heat alone. High pressurization represents an alternative food processing method, and can be utilized in meat processing [9]. We have already

reported that high pressure-treated fish meat and *surimi* (ground fish meat) gel are smooth and have moderate elasticity in terms of textural properties. High pressurization causes the transformation to gel by denaturation of myosin in fish protein [10, 11]. Although beef and pork are also good sources of protein, they are often difficult to masticate and swallow as a bolus by the elderly and dysphagic patients. We hypothesize that an appropriate gel for dysphagic patients may be produced by high pressure treatment of minced meat mixed with water.

To develop a new type of processed meat for the elderly and dysphagic patients, we prepared a soft gel that can be mashed easily by the tongue and hard palate, by mixing minced meat with water at a ratio of 1:1 followed by high pressure and heat treatments (1:1 pressurized and heat-treated gel; 1:1 PH gel). We also prepared a slightly elastic gel with some chewiness by mixing minced meat with water at a ratio of 1:0.5 (1:0.5 PH gel). Furthermore, heated meat patty and heated meat paste served conventionally as dysphagia diets in facilities for the elderly and in hospitals [12, 13] were also prepared and compared with the PH gels. We then examined the physical properties and performed a sensory evaluation test of these four minced meat samples, and performed videofluoroscopic examination of swallowing (VF) while participants swallowed the gel. We investigated whether the 1:1 PH gel would be suitable as a dysphagia diet.

Methods

1. Preparation of meat samples

The procedures for the preparation of the four minced pork meat samples (1:0.5 PH gel, 1:1 PH gel, heated patty, and heated paste) are shown in Figure 1.

The 1:0.5 and 1:1 PH gels: After pork was minced, 50% volume of water (1:0.5), 1.5% NaCl and rosemary (for flavor) were added to one portion of minced pork (1:05 PH gel); and 100% volume of water (1:1), 1.5% NaCl and rosemary were added to the other portion (1:1 PH gel). Each sample was ground again, pressurized at 400 MPa for 20 min using a food pressure testing machine (MFP-7000, Mitsubishi Heavy Industries Ltd., Japan) and then steamed in a superheated steam oven (AX-HC1, Sharp, Japan) until the center reached 80°C.

Heated patty: After pork was minced, 10% volume of water, 0.9% NaCl and rosemary were added to the meat. The sample was ground again, and then heated in boiling water at 94–95°C for 10 min, until the center reached 80°C.

Heated paste: After pork was minced, 100% volume of water, 0.9% NaCl and rosemary were added. The sample was ground again, and then heated at 94–95°C in a double-boiler until the sample reached 80°C. It was then mixed in a mixer to form a paste.

2. Measurement of textural properties

The textural properties of four pork meat samples (1:0.5 PH gel, 1:1 PH gel, heated patty and heated

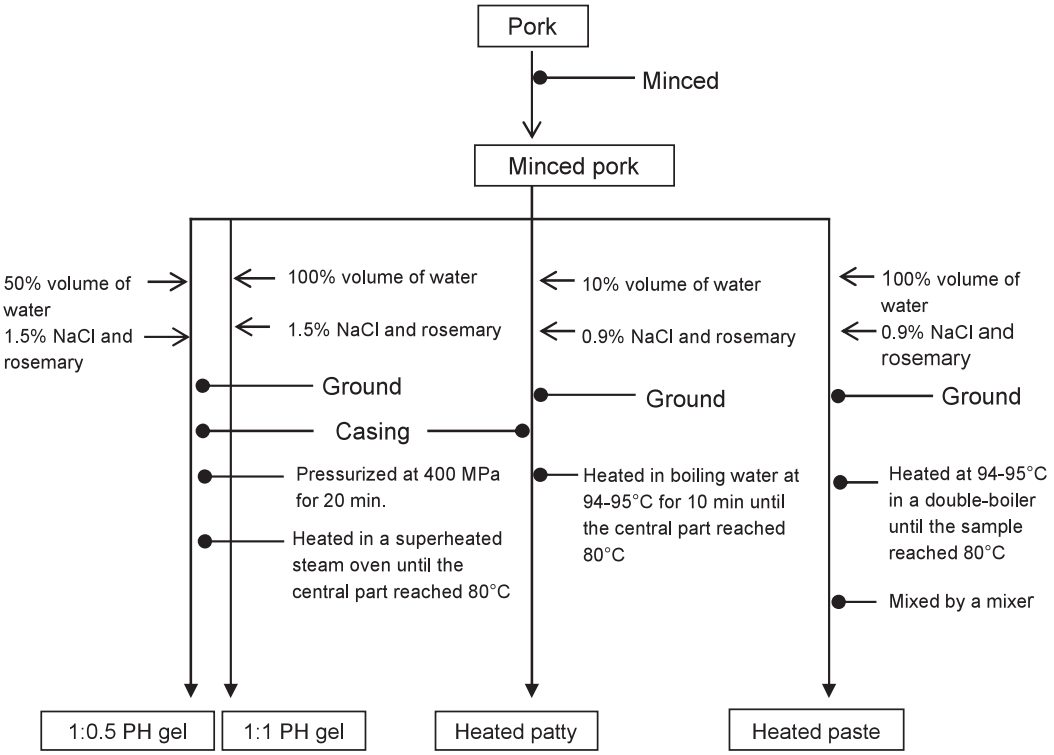

Figure 1. Preparation of 1:0.5 and 1:1 PH gels, heated patty and heated paste.
PH gel: pressurized and heat-treated meat gel.

paste) were measured with a creep meter (RE-2-33005S, Yamaden, Japan) for hardness, cohesiveness and adhesiveness. The test conditions were as follows: the plunger was a disk 20 mm in diameter for the PH gels (heated paste was encased in a stainless steel laboratory dish 40 mm in diameter and 15 mm in height); the test speed was 1 mm/sec; and the deformation rate was 70% for the PH gels and 80% for the heated patty [14, 15]. Texture was measured according to the dietary criteria of Food for Special Dietary Uses for dysphagic patients provided by the Ministry of Health, Labour and Welfare in Japan [16]. The load of the creep meter for measurement was 20 N. For heated patty only, the deformation rate was 80% and the plunger was 10 mm in diameter to avoid overload.

3. Sensory evaluation

Thirteen healthy female subjects 21 to 24 years of age underwent sensory evaluation tests, rating eight aspects of the four pork minced meat samples on a five-point scale [14, 15]: flavor (−2: very bad to +2: very good), softness (−2: very hard to +2: very soft), elasticity (−2: little elastic to +2: much elastic), smoothness (−2: coarse to +2: very smooth), easiness to mash by the tongue (−2: hard to mush to +2: easy to mush), easiness to swallow (−2: hard to swallow to +2: easy to swallow), residues in the oral cavity (−2: plenty of residues to +2: no residue), and overall acceptance (−2: very bad to +2: very good). The subjects were uninformed about which sample was being tested during the sensory evaluation test.

4. Videofluoroscopic examination of swallowing

To increase the visibility of a bolus during VF examination, 20% (w/w) of barium sulfate powder (Baribright P, Sakai Chemical Industry, Japan) was added to the four pork minced meat samples. A preliminary examination revealed there were no significant differences in the textural properties between the four samples with and without 20% (w/w) of barium sulfate powder.

Five healthy female subjects and 5 patients with dysphagia (1 male and 4 females) who were referred to the dysphagia clinic in the Department of Rehabilitation Medicine, University Hospital of Occupational and Environmental Health participated in the VF study. The diagnoses of the patients were amyotrophic lateral sclerosis in one, dermatomyositis in two, and multiple system atrophy in two.

During VF, the subjects were asked to hold a spoonful of each sample (approximately 5 g) in the mouth and masticate it at the sign of starting, and then swallow at their own free will. One of the authors (Y.M.) played back the video after VF and observed details of swallowing on the display: the number of mastications until the first swallow, the number of gulps while swallowing one piece of the sample, and the total transit time. The bolus transit time was measured based on the VF lateral view at 30 frames/sec, using a video editing software program (Premiere Pro CS3, Adobe Systems, Japan). According to the Process Model paradigm [17−19], the transit time was evaluated by dividing the oropharynx into four regions: oral cavity (OC), upper oropharynx (UOP), valleculae (VAL), and hypopharynx (HYP), as shown in Figure 2.

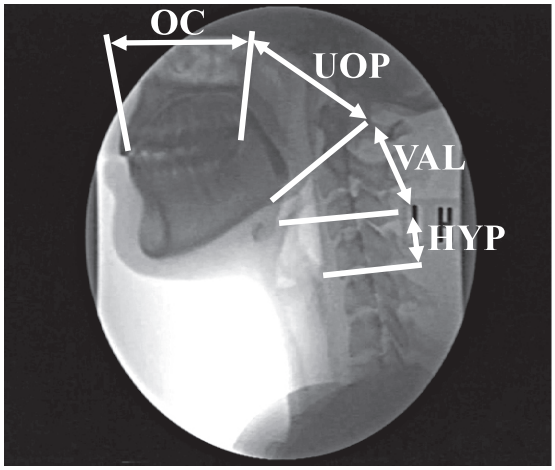

Figure 2. Four regions of the oral cavity and pharynx
OC: oral cavity, UOP: upper oropharynx (behind the fauces but above the inferior border of mandible), VAL: valleculae area (below the inferior border of the mandible but above the hypopharynx), HYP: hypopharynx (below the valleculae but above the entrance of esophagus).

5. Ethics

This study was approved by the in-house ethics committee of Nakamura Gakuen University and the experiments were performed in accordance with the Declaration of Helsinki, after obtaining informed consent from all subjects.

6. Statistical analysis

The data were analyzed with a statistical software program (SPSS 16.0J, SPSS Inc., Chicago, USA). The differences in textural properties, sensory scores and VF were analyzed using one-way ANOVA and Tukey's multiple range test. Student's t-test was used for analysis of VF. The correlation between textural properties and bolus transit times was measured by Pearson's correlation coefficient. The differences were determined to be significant for p values less than 0.05.

Results

1. Textural properties of PH gels, heated patty, and heated paste

The textural properties of the four pork minced meat

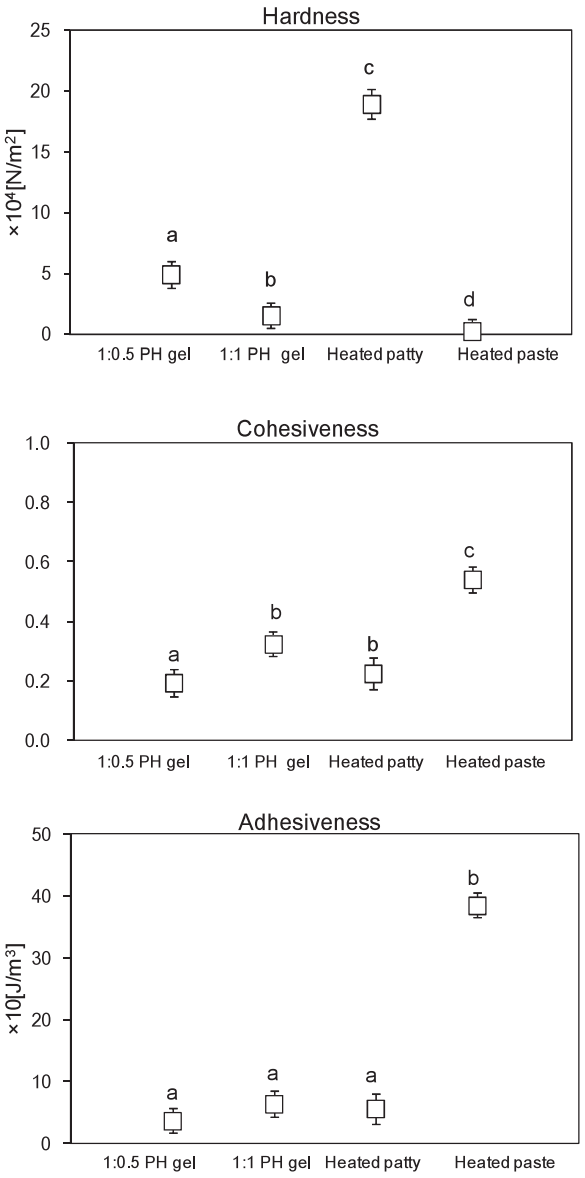

Figure 3. Textural properties of 1:0.5 and 1:1 PH gels, heated patty and heated paste.
PH gel: pressurized and heat-treated meat gel, ⊟: mean ± SD, n=6. Values not sharing a common superscript letter (a, b, c, d) are significantly different (p<0.05) as assessed by Tukey's multiple range test.

samples are shown in Figure 3. The 1:0.5 PH gel (4.98 N/m^2) and the 1:1 PH gel (1.53 N/m^2) were softer than the heated patty (18.92 N/m^2), and less cohesive and less adhesive than the heated paste (one-way ANOVA, Tukey's multiple range test, p<0.05). The 1:1 PH gel was softer and more cohesive than the 1:0.5 PH gel (one-way ANOVA, Tukey's multiple range test, p<0.05).

2. Sensory evaluation of PH gels, heated patty, and heated paste

The results of the sensory evaluation test of the four samples are shown in Figure 4. The PH gels were evaluated to be elastic, fine in density, smooth, and easy to swallow, leaving no residue after swallowing, and these features were especially prominent for the 1:1 PH gel. The heated patty had good acceptance in flavor, but was evaluated to be hard and not easy to swallow, with some residue remaining in the oral cavity. The heated paste was evaluated to be soft, easy to mash with the tongue, but not good in flavor, and left residue after swallowing. The overall acceptance of both PH gels was significantly better than that of the heated paste (one-way ANOVA, Tukey's multiple range test, p<0.05), and the 1:1 PH gel was rated especially high in individual items.

3. Videofluoroscopic examination of swallowing

The numbers of mastication and gulps and the transit time through the oropharynx for the four pork minced meat samples in healthy subjects and dysphagic patients are shown in Table 1-1.

When healthy subjects swallowed the samples under VF, the numbers of mastication for the 1:0.5 and 1:1 PH gels were higher than those for the heated paste; the number of gulps for the 1:1 PH gel was less than that for the heated paste; and the transit time through the oropharynx for the 1:1 PH gel was shorter than those for the heated patty and the 1:0.5 PH gel. The transit time through the oropharynx was the shortest for the heated paste, followed by the 1:1 PH gel, the 1:0.5 PH gel and the heated patty, in that order. Dysphagic patients showed a similar tendency with regard to the numbers of mastication and gulps and the transit time through the oropharynx compared to healthy subjects, and there was no significant difference in the number of swallowing among four samples.

The bolus transit times in the four regions (oral and pharynx areas defined by the Process Model) for the healthy subjects and dysphagic patients are shown in Table 1-2. The correlation between the textural data and transit times in the four regions for both groups of subjects is shown in Table 2. An example of VF is shown in Figure 5. With the heated patty, many residues remained in the valleculae and at the entrance of the esophagus. The 1:1 and 1:0.5 PH gels were transported smoothly in an aggregated bolus, and only a little residue remained compared with the other samples. The heated paste adhered to the mucous membrane in the valleculae and at the entrance of the esophagus.

Discussion

1. Textural properties

Regarding the textural properties of the meat samples in terms of hardness, cohesiveness and adhesiveness, the 1:1 PH gel conformed to the dietary criterion II. The heated paste was the softest among the four samples because of its viscous sol, and conformed to the dietary criterion I. The PH gels were

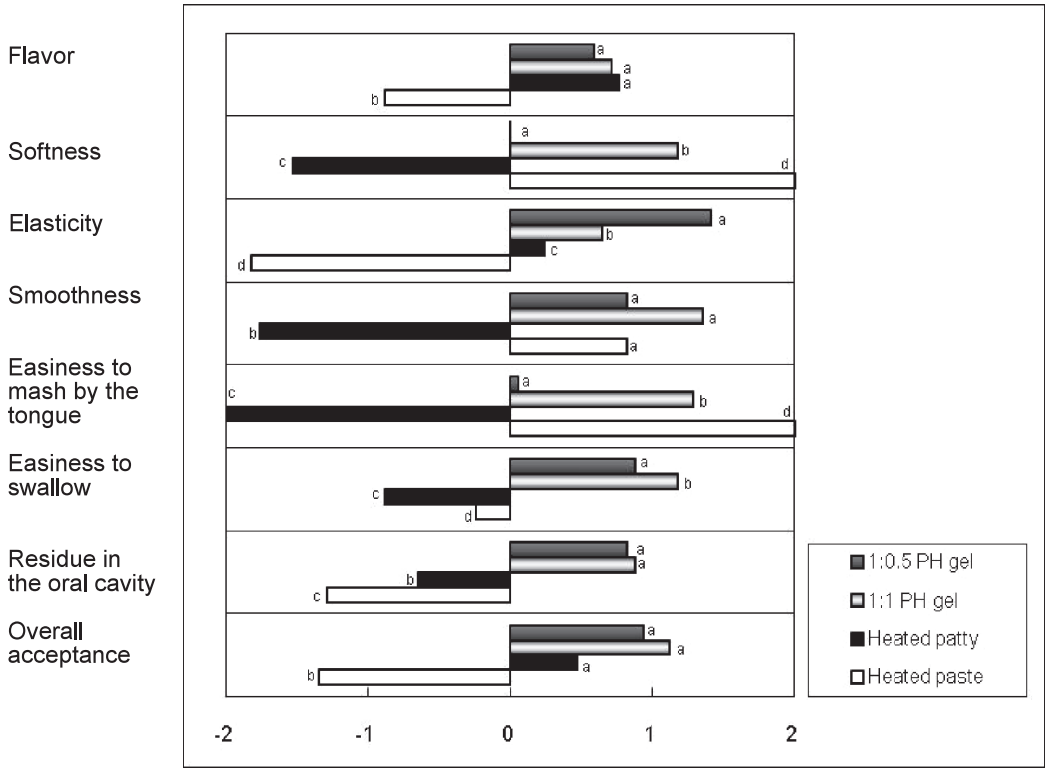

Figure 4. Sensory evaluation test of 1:0.5 and 1:1 PH gels, heated patty and heated paste.
PH gel: pressurized and heat-treated gel.
Data are expressed as means. Values not sharing a common superscript letter (a, b, c, d) are significantly different (p<0.05) as assessed by Tukey's multiple range test.

Table 1. Videofluoroscopic swallow studies of 1:0.5 PH gel, 1:1 PH gel, heated patty and heated paste

1) Numbers of mastication and swallowing, and transit time through oropharynx in healthy subjects and dysphagic patients

	Sample	Number of mastications	Number of gulps	Transit time through oropharynx (sec)
Healthy subjects	1:0.5 PH gel	22.00±2.07 [a]	2.95±0.67 [a]	18.46±3.08 [a]
	1:1 PH gel	19.00±2.28 [a]	2.15±0.10 [b]	13.33±3.24 [a]
	Heated patty	31.00±4.86 [a]	3.88±0.49 [a]	25.13±6.57 [a]
	Heated paste	4.40±1.02 [b] *	3.80±1.33 [a] *	5.10±1.09 [b]
Dysphagic patients	1:0.5 PH gel	23.60±8.19 [a]	2.80±0.40	18.19±4.56 [a]
	1:1 PH gel	14.57±2.54 [a]	3.06±0.64	12.33±2.32 [a]
	Heated patty	33.03±10.52 [a]	3.74±0.62	25.39±5.15 [a]
	Heated paste	3.94±1.33 [b]	3.00±0.63	6.60±1.70 [b]

2) Bolus transit times in four regions of the oropharynx

	Sample	OC (sec.)	UOP (sec.)	VAL (sec.)	HYP (sec.)	UOP+VAL (sec.)	UOP+VAL+ HYP (sec.)
Healthy subjects	1:0.5 PH gel	17.04±3.07 [a] * *	0.54±0.46 ** *	0.26±0.36 *	0.15±0.05	0.81±0.77 ** *	0.96±0.75 ** *
	1:1 PH gel	12.49±3.03 [a]	0.63±0.48	0.17±0.13	0.15±0.06	0.80±0.61	0.95±0.58
	Heated patty	20.77±7.01 [a]	2.80±2.23	0.26±0.36	0.17±0.06	3.06±2.21	3.22±2.19
	Heated paste	3.64±1.28 [b]	0.59±0.62	1.80±2.80	0.49±0.86	2.39±3.41	2.88±3.56
Dysphagic patients	1:0.5 PH gel	9.41±4.22 *	5.10±3.11 [a] * **	2.25±2.34 **	0.16±0.04	7.36±4.39 [a] ** *	7.51±4.41 [a] **
	1:1 PH gel	6.44±3.73	3.50±2.92 [a]	1.37±1.31	0.15±0.01	4.87±3.64 [a]	5.02±3.64 [a]
	Heated patty	9.84±3.68	10.41±5.55 [b]	3.41±1.61	0.16±0.03	13.82±5.97 [b]	13.98±5.95 [b]
	Heated paste	2.45±1.21	1.09±0.51 [a]	2.29±2.25	0.13±0.03	3.38±2.37 [a]	3.51±2.40 [a]

PH gel: pressurized and heat-treated meat gel, OC: oral cavity, UOP: upper oropharynx, VAL: valleculae, HYP: hypopharynx. Data are expressed as mean ± SD; n=5. Values not sharing a common superscript letter (a, b) are significantly different (p<0.05) as assessed by Tukey's multiple range test. Student's t-test was used to compare healthy subjects with dysphagic patients, significantly different at *: p<0.05, **: p<0.01.

Table 2. Correlation between textural data and transit times in four regions of oropharynx in healthy subjects and dysphagic patients

		OC	UOP	VAL	HYP	UOP+VAL	UOP+VAL+HYP
Healthy subjects	Hardness	0.853**	0.555*	-0.300	0.277	0.381	0.401
	Cohesiveness	-0.773**	-0.351	0.096	-0.164	-0.218	-0.204
	Adhesiveness	-0.623**	-0.129	0.139	-0.019	0.023	-0.005
Dysphagic patients	Hardness	0.449*	0.827**	0.347	0.372	0.813**	0.813**
	Cohesiveness	-0.238	-0.761**	-0.294	-0.252	-0.753**	-0.753**
	Adhesiveness	-0.199	-0.527*	-0.131	-0.359	-0.454*	-0.454*

OC: oral cavity, UOP: upper oropharynx, VAL: valleculae, HYP: hypopharynx. Correlation between textural data and transit time was determined by Pearson's correlation coefficients. *: significantly different at $p<0.05$, **: significantly different at $p<0.01$.

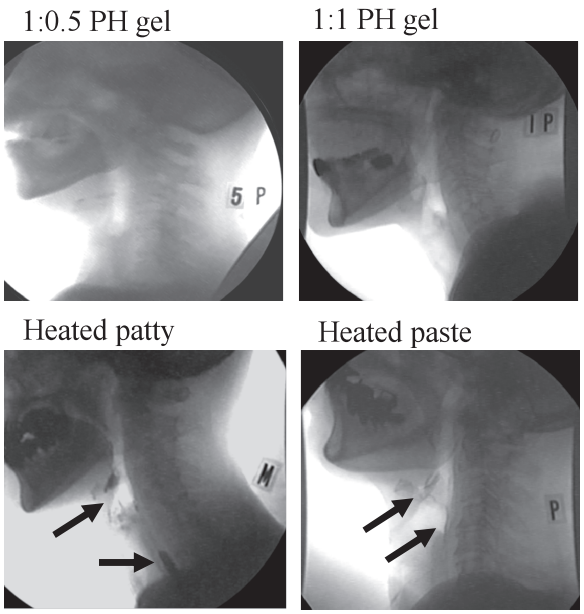

Figure 5. Videofluoroscopic examination of swallowing in a patient with dysphagia.
PH gel: pressurized and heat-treated meat gel.
The residue in the pharyngeal was less for the PH gels than for the heated patty and the heated paste.

less adhesive and cohesive than the heated paste, and were softer than the heated patty. Studies on the relation between textural properties and swallowing function have shown that food that is soft, less adhesive and high in coagulation is less sticky, smooth and comfortable in the throat [20, 21]. It is also reported that a homogeneous and deformable bolus is effective for patients with pharyngeal disorder [22]. From our findings, the 1:1 PH gel gathers easily as a bolus because it hardly adheres to the oral cavity and the pharynx, and the bolus passes easily through the pharynx because it is soft and deformable.

2. Sensory evaluation

From the results of the sensory evaluation test on the four samples, the 1:1 PH gel was evaluated to be elastic, fine in density, smooth, and easy to swallow, leaving no residue after swallowing. These results are consistent with the textural properties. Therefore the PH gels were evaluated highly for both texture and taste, and these features have the same tendency as fish surimi gel produced by high pressure [10, 11].

3. Videofluoroscopic examination of swallowing

In the VF study, the transit time through the oropharynx was the shortest for the heated paste in both healthy subjects and dysphagic patients, because the paste hardly needed mastication and was retained in the oral cavity region for a short duration.

In terms of the bolus transit times through the four regions of the oropharynx, the transit times through the UOP+VAL and UOP+VAL+HYP were almost the same for the 1:0.5 PH and 1:1 PH gels in healthy subjects. However the 1:0.5 PH gel tended to take a longer time to pass through the UOP+VAL and UOP+VAL+HYP than the 1:1 PH gel in dysphagic patients. We suspect that hardness of the gel may influence the transit of the bolus from UOP to HYP in dysphagic patients.

In the analysis of the relation between the texture data of each sample and the transit times through the four regions of the oropharynx, a correlation between hardness of the sample and transit time in OC was observed in healthy subjects. On the other hand, a correlation between hardness and OC transit time and between hardness and UOP transit time was detected in dysphagic patients. The correlation coefficient between hardness and UOP transit time was especially high, indicating that more time is needed to pass through UOP with increasing hardness.

Judging from the number of mastications, swallowing time and transit time through the oropharynx, our data suggest that healthy subjects may form a bolus of food in the mouth and pass it through the pharynx smoothly regardless of the consistency of the food. A possible reason is that food is adjusted to an appropriate consistency and texture by mastication, and consequently the bolus is transported to the pharynx smoothly. On the other hand, dysphagic patients cannot masticate sufficiently or adjust the food with saliva in the oral

cavity. These pathophysiological conditions in dysphagic patients cause incomplete bolus formation and a delay in swallow reflex during eating.

In amyotrophic lateral sclerosis [23], dermatomyositis [24] and multiple system atrophy [25], dysfunctions such as impaired tongue movement, inadequate pharyngeal pressure, and reduced laryngeal elevation due to muscular atrophy and paralysis have been reported [26]. For non-homogenous food, the bolus formed by mastication may pass into the pharynx before swallowing reflex occurs, increasing the risk of aspiration [22]. However, even in dysphagic patients, the bolus of the 1:1 PH gel reached an appropriate size and stayed in the pharynx until swallowing reflex occurred, and was finally swallowed. Furthermore, the 1:1 PH gel had the shortest VAL transit time among the four samples, suggesting that swallowing reflex was induced easily. In addition, VF showed little residue remaining after swallowing the 1:1 PH gel. These results indicate that the 1:1 PH gel may have the lowest risk of aspiration. Therefore the PH gel, especially the 1:1 PH gel, is the most suitable form as a dysphagic diet.

Conclusions

The textural properties of the 1:1 PH gel, which conforms to the dietary criterion II, indicated that it was the softest and least adhesive among the four samples (heated patties, heated paste, 1:0.5 PH gel, and 1:1 PH gel). In the sensory test, the 1:1 PH gel was evaluated to be elastic, smooth, and easy to swallow, with hardly any residue remaining. Furthermore, VF study in dysphagic patients showed that the 1:1 PH gel had the shortest transit time in the VAL, with very little residue in the oropharynx. Therefore, we confirmed that transformation of material properties by high pressurization can be applied to the development of pressurized and heat-treated meat gels for dysphagic patients, and proved that the meat gels are suitable as a dysphagia diet.

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