Original Research

Evaluation of Swallowing Function Using Ultrasound Diagnostic Methods

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Clinical significance

The ultrasound image with swallowing sounds showing movements of the epiglottis and the test food was confirmed to be useful for a screening for dysphagia as well as X-ray images by videofluorography.

ABSTRACT

Purpose : The purpose of this study was to develop an objective method of evaluating the swallowing function.

Materials and Methods : Ten healthy, fully dentate males (average age 28.6 ± 3.5 years old) were selected as subjects. General-purpose ultra-sound diagnostic equipment was used with a 5 MHz electronic convex sector scanning probe to observe tongue movement while food was being swallowed. The sounds associated with swallowing were recorded using a heart sound microphone connected to ultra-sound diagnostic equipment. The tongue movements and swallowing sounds were simultaneously recorded on chart paper, and analyzed by plotting six inflection points (T_0 , T_1 , T_2 , T_3 , T_4 and T_5) of the movement curve, and two beginning points of the swallowing sounds (S_1 and S_2) using a digitizer. X-ray images using videofluorography were recorded simultaneously with ultrasound images in three of the ten subjects.

Results : It was confirmed that all the data from the ten subjects were reproducible. There were statistically significant correlations between T_{t4} and S_{t1} , and T_{t4} and S_{t2} , ($p < 0.001$). S_{t1} always preceded T_{t4} . The VF image S_1 indicated that the point in time when the epiglottis was about to shut and T_4 coincided with the time when the last of the test food reached the esophagus.

Conclusion : Our results suggested that this evaluation method could be useful for the diagnosis of swallowing.

Key words

swallowing function, tongue movement, swallowing sound, ultrasound diagnostic equipment

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INTRODUCTION

Feeding and swallowing dysfunction is of greater concern now than in the past due to the increased numbers of elderly people¹⁾ and the potential for increased risk of pneumonia^{2,3)} from dysphagia with frequent aspiration. Aspiration pneumonia in the elderly is caused by the decrease in the deglutition reflex and the cough reflex.

Common methods for assessing dysphagia and aspiration are clinical medical examinations and history using questionnaires and tests involving drinking water⁴⁻⁶⁾. Cervical auscultation is frequently used in clinical examinations⁷⁾. However, these methods are subjective and cannot objectively evaluate the degree of swallowing function. Videofluorographic evaluation is the most reliable⁸⁾, but exposure of the subjects to radiation is unavoidable and reproducibility is difficult^{9,10)}.

While a team approach by physicians, dentists, occupational therapists, speech therapists and other health professionals is recommended for patients with dysphasia, it is important to have common criteria to objectively evaluate swallowing in each patient.

The purpose of this study was to establish an objective method of evaluating the swallowing function and the influence of the viscosity of test foods. The proposed method was based on the measurements of tongue movements and swallowing sounds during deglutition.

MATERIALS AND METHODS

Subjects

Ten healthy, fully dentate males (average age: 28.6 ± 3.5 years old) were selected as subjects for developing standard values for tongue movement and swallowing sounds during normal

deglutition. The experiments were performed with informed consent.

Test Food for Swallowing Evaluation

Test foods were made by dissolving Mousse Up[®] (Food Care Ltd., Kanagawa, Japan) in amounts of 1.5, 2, 3, and 6 g into 30 ml water. These foods were named "L, M 1, M 2, and H," respectively. The main ingredient of Mousse Up[®] is a processed starch that is mixed with different amounts of water to get a variable coefficient of viscosity. According to the product information, the viscosity of L has the same coefficient of viscosity as honey, M 1 as mayonnaise, M 2 as mousse, and H as mashed potatoes.

The subjects were requested to rank the four kinds of test foods according to the subjective difficulty of swallowing them on a scale from 4 (most difficult) points to 1 (least difficult) point.

Recording Tongue Movements and Swallowing Sounds

To observe the tongue movements while the subjects swallowed the test food, general-purpose ultra-sound diagnostic equipment (SSD-630, Aloka, Tokyo, Japan) was used with a 5 MHz electronic convex sector scanning probe (UST-935 N-5, Aloka) (Fig. 1). The highest point of the tongue surface in the brightness-modulation sagittal image (B-mode) was used to fix the probe (Fig. 2, left side). The rising/falling movements of the highest point of the tongue surface were recorded by motion-modulation imaging (M-mode) (Fig. 2, right side) as the sagittal image on an ultrasound recorder (SSZ-320, Aloka) (Fig. 3). The paper speed was 50 mm per second.

A heart sound microphone (MA-250, Aloka) was connected to the ultra-sound diagnostic equipment through a physiological signal unit (EU-5018, Aloka). The swallowing sounds

were recorded at a lateral position (30 mm from the thyroid cartilage) (Fig. 3).

X-ray images using videofluorography (KXO-50 N, Toshiba, Tokyo, Japan) were recorded simultaneously with the ultrasound images in three of the ten subjects. Amidotri-

zoic acid (Gastrografin®, Schering, Germany) was added to the test food as a contrast medium.

Swallowing Test

Each subject was seated upright and instructed to swallow the four kinds of test food on sublingual papilla. The trials were repeated five times per test food.

The tongue movements and swallowing sounds were recorded on the chart paper and analyzed by plotting six inflection points (T_0 , T_1 , T_2 , T_3 , T_4 and T_5) of the movement curve

Fig. 1 Measurement system for tongue movement and swallowing sound

Fig. 2 B/M mode image

Fig. 3 Example of recorded chart

Fig. 4 Measurement of tongue movement and swallowing sound

and two points at the initiation of the swallowing sounds (S_1 and S_2) using a digitizer (Fig. 4). The point T_0 was used as a zero point of the measurements. The times from T_0 to T_1 , T_2 , T_3 , T_4 , T_5 , S_1 and S_2 were represented as T_{t1} , T_{t2} , T_{t3} , T_{t4} , T_{t5} , S_{t1} and S_{t2} .

The data were input into a personal computer and analyzed using a custom-made analysis program that converted the X-Y data from the digitizer (X=time; Y=distance). The resolution of the digitizer was 0.2 mm, and the measurement error of this system was 6 msec.

Statistical Analysis

Statistical analysis of the repeatability of each parameter was performed by the Kruskal-Wallis test, while the subjective evaluation of the difficulty of swallowing was performed by one-way analysis of variance (ANOVA) and the Scheffé's test. Regression analysis was used to determine the correlation between parameters.

RESULTS

The results were statistically analyzed from several perspectives. For the subjective difficulty of swallowing, point H was statistically the highest (3.9 point), and point L was the lowest (1.0 point) ($p < 0.01$). Point M 2 was statisti-

Table 1 Swallowing difficulty of four kinds of test food

Viscosity	Food codes			
	L	M 1	M 2	H
Mean	1.0	2.3	2.8	3.9
S.D.	0.0	0.5	0.7	0.3

Table 2 Summary of ANOVA

	Sum of squares	df	Mean squares	F	Sig.
Between groups	38.556	3	12.852		
Within groups	6.444	32	0.201	63.816	0.000
Total	45.000	35			

Table 3 Multiple comparisons (Scheffé's test results)

Swallowing difficulty	N	Subset for alpha=0.01		
		1	2	3
1	9	1.0000		
2	9		2.3333	
3	9		2.7778	
4	9			3.8889
Significance		1.000	0.044	1.000

cally higher than that of M 1 ($p < 0.05$) (Tables 1–3). In each test food, the parameters (T_{t1} , T_{t2} , T_{t3} , T_{t4} , T_{t5} , S_{t1} and S_{t2}) were compared and investigated to determine to what extent they were influenced by the viscosity of the test food. There were no significant differences in the mean values of each parameter among the four test foods (Table 4). For T_{t1} , T_{t2} , T_{t3} , the standard deviations of each parameter in the test food L were the lowest of all the test foods (Table 5). For T_{t4} , T_{t5} , S_{t1} , S_{t2} , the standard deviations of each parameter in the test food H were the lowest of all the test foods (Table 5).

It was confirmed that all the data were reproducible (Table 6); there were no significant differences in any of the parameters (T_{t1} , T_{t2} , T_{t3} , T_{t4} , T_{t5} , S_{t1} and S_{t2}) in each measurement by test food H.

Among the parameters, there was a statisti-

Table 4 Summary of ANOVA for each parameter

		Sum of Square	df	Mean Square	F	Sig.
T _{t1}	Between groups	730.8	3	243.6		
	Within groups	205,282.1	196	1,047.4	0.233	0.874
	Total	206,013.0	199			
T _{t2}	Between groups	7,342.4	3	2,447.5		
	Within groups	563,901.0	196	2,877.1	0.851	0.468
	Total	571,247.3	199			
T _{t3}	Between groups	4,982.1	3	1,660.7		
	Within groups	839,369.9	196	4,282.5	0.388	0.762
	Total	844,352.0	199			
T _{t4}	Between groups	70,580.3	3	23,526.8		
	Within groups	4,862,888.6	196	24,810.7	0.948	0.418
	Total	4,933,458.9	199			
T _{t5}	Between groups	67,384.2	3	22,461.4		
	Within groups	5,033,153.8	196	25,679.4	0.875	0.455
	Total	5,100,538.0	199			
S _{t1}	Between groups	68,939.1	3	22,979.7		
	Within groups	2,956,655.5	196	15,085.0	1.523	0.210
	Total	3,025,594.6	199			
S _{t2}	Between groups	53,422.9	3	17,807.6		
	Within groups	4,673,333.9	196	23,843.5	0.747	0.525
	Total	4,726,756.8	199			

Table 5 Mean and S.D. for each parameter

		T _{t1}	T _{t2}	T _{t3}	T _{t4}	T _{t5}	S _{t1}	S _{t2}
L	Mean	58.4	114.9	174.7	477.8	537.4	279.8	437.6
	S.D.	29.8	49.1	58.3	140.6	140.8	125.8	156.1
M 1	Mean	58.4	112.2	178.1	514.1	564.5	312.8	459.8
	S.D.	32.3	51.7	71.5	194.2	202.5	157.3	188.1
M 2	Mean	63.1	127.4	188.3	519.3	581.2	280.5	445.2
	S.D.	33.9	62.9	68.4	175.3	173.6	118.7	163.3
H	Mean	60.1	122.6	180.9	480.9	538.8	261.2	414.6
	S.D.	33.3	49.7	62.8	105.1	108.3	75.5	94.6

(Unit : msec)

cally significant correlation between T_{t4} and S_{t1}, T_{t4} and S_{t2} (p<0.001) (Table 7). S_{t1} always preceded T_{t4} (Fig. 5).

A sequence of photographs taken at 1/30-second intervals was obtained from the Echo images and VF (Fig. 6). It was ascertained from the VF images that S₁ coincided with the point of time when the epiglottis was about to

shut, and T₄ coincided with the time when the last of the test food had just reached the esophagus.

DISCUSSION

The standard deviation of each parameter in test food H was lower than that of the other test

Table 6 Summary of Kruskal-Wallis test

	T _{t1}	T _{t2}	T _{t3}	T _{t4}	T _{t5}	S _{t1}	S _{t2}
Chi-Square	0.139	0.818	1.730	1.542	3.419	0.813	0.921
df	4	4	4	4	4	4	4
Asymptotic significance	0.998	0.936	0.785	0.819	0.490	0.937	0.922

Table 7 Correlations

		T _{t1}	T _{t2}	T _{t3}	T _{t4}	T _{t5}	S _{t1}
T _{t1}	Pearson correlation Significance N						
T _{t2}	Pearson correlation Significance N	0.842** 0.000 200					
T _{t3}	Pearson correlation Significance N	0.649** 0.000 200	0.793** 0.000 200				
T _{t4}	Pearson correlation Significance N	0.048 0.500 200	0.146** 0.039 200	0.411** 0.000 200			
T _{t5}	Pearson correlation Significance N	0.053 0.457 200	0.160* 0.024 200	0.402** 0.000 200	0.965** 0.000 200		
S _{t1}	Pearson correlation Significance N	0.065 0.360 200	0.137 0.053 200	0.421** 0.000 200	0.797** 0.000 200	0.745** 0.000 200	
S _{t2}	Pearson correlation Significance N	0.013 0.851 200	0.084 0.237 200	0.359** 0.000 200	0.787** 0.000 200	0.725** 0.000 200	0.865** 0.000 200

*p<0.05, **p<0.001

foods for T_{t4}, T_{t5}, S_{t1}, S_{t2} (Table 5). It was speculated that the values of T_{t1}, T_{t2} and T_{t3} related to the swallowing difficulty, and the values of T_{t4}, T_{t5}, S_{t1} and S_{t2} related to aspiration, which means that stable measurement values can be obtained for this method by using the test food H for T_{t4}, T_{t5}, S_{t1} and S_{t2}. An important factor in the diagnosis of swallowing is to evaluate the possibility of aspiration. From this point of view, we selected test food H from the four test foods.

Swallowing is commonly separated into three stages : buccopharyngeal, pharyngeal, and esophageal^{11,12)}. However, Leopold and Kagel¹³⁾ proposed a paradigm that incorporates the three

stages of deglutition into a five-stage process of ingestion : anticipatory stage, preparatory stage, lingual stage, pharyngeal stage and esophageal stage. Their paradigm could be supported because the tongue and teeth play an important role in swallowing as well as in mastication. Moreover, tooth contact is commonly confirmed in swallowing.

The "preparatory stage" includes mastication controlled by various proprioceptors and the upper central nervous system. Under these controls, the mandible moves rhythmically¹⁴⁾, and bolus formation and manipulation are provided by the tooth, tongue, and buccinator muscle for deglutition.

In the “lingual stage,” the lingual edges appose the hard plate anteriorly and laterally as the tongue makes contact¹³⁾. In our study, we judged T_3 to be the end of this stage, when the bolus was squeezed toward the oropharynx, as indicated in the VF images (Fig. 6). Then, the bolus was squeezed toward the oropharynx.

In the “pharyngeal stage,” the tongue approximates the posterior pharyngeal wall, resulting in a tight velopharyngeal seal. The epiglottis shuts in anticipation of the bolus. S_1 was found to be the beginning of this sound, as shown in the VF images (Fig. 6). Then, the bolus was pro-

jected to the posterior pharyngeal wall and transported through the pharynx to the esophagus. The results indicated that S_2 is the beginning of this sound (Fig. 6). As the VF images showed, T_4 coincided with the point in time when the last of the test food had just reached the esophagus (Fig. 6).

The results showed that S_{t1} always preceded T_{t4} (Fig. 5), which meant that the subjects had normal deglutition reflex. If T_{t4} occurred before S_{t1} , aspiration was possible.

In Fig. 5, the inclination of the straight regression line in each test food was in the order of the degree of viscosity. The inclination of the regression line meant the extension of the time lag of T_{t4} and S_{t1} . On the other hand, the difficulty of swallowing each test food was in the order of the degree of viscosity, as mentioned above (Tables 2 and 3). Although there was no statistical significance in the relationship between each parameter and the degree of viscosity of the test food, the inclination of the straight regression line showing the relationship between T_{t4} and S_{t1} can be considered an index of the swallowing difficulty. It was speculated that the reason there is no statistical significance between each parameter and the viscosity of the test foods was that the subjects in the investigation swallowed normally.

Fig. 5 Relationship between T_{t4} and S_{t1}

Fig. 6 Echo and VF images

This investigation suggested that our evaluation method could be useful for the diagnosis of swallowing difficulties.

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