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Temporal Measurements Of Pharyngeal Swallowing In Normal Populations

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Abstract

The purpose of this investigation was to examine the temporal differences among three measures of pharyngeal stage transition in 40 normal subjects. The measures were (1) Pharyngeal Delay Time (PDT), (2) Stage Transition Duration (STD), and (3) Delayed Pharyngeal Swallow (DPS). Results showed a significant difference between younger and older subjects for PDT and STD but not for DPS. No gender differences were observed. These data on normal subjects will be used for comparisons with stroke patients in future research.

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Temporal Measurements of Pharyngeal Swallowing in Normal Populations

The dynamics of oropharyngeal swallowing are both simultaneous and sequential in nature. Historically, it has been broken down into stages (i.e., oral preparatory, oral, and pharyngeal) and has been further delineated into specific physiologic terms that define the movement of the bolus through the biomechanical process of swallowing [1]. Biomechanical and temporal measurements of swallowing physiology are designed to (1) promote research on normal and abnormal physiology, (2) provide detailed, comprehensive diagnostic tools for patients with dysphagia, and (3) help the clinician develop management and

treatment plans that are specific to the physiologic problems. Normative data for many temporal measures have been obtained and reported [1–5].

The videofluoroscopic swallowing examination (VFSE) provides X-ray imaging of the oral and pharyngeal stages that can be recorded onto video- tape or digital imaging systems. VFSEs can then be analyzed frame-by-frame, recording the time (in milliseconds) that specific physiologic events occur in relation to one another. In addition, judgments of bolus flow, such as residue in the oral cavity or pharynx, and misdirection of the bolus, such as laryngeal penetration and aspiration, can be made.

As a bolus is propelled from the oral cavity into the pharyngeal cavity, the pharyngeal swallow should be triggered. Triggering of the pharyngeal swallow means that the hyolaryngeal complex will begin to rise and the laryngeal vestibule will close at three levels: (1) the epiglottis will close over the arytenoid cartilages, (2) the false vocal folds will close and the arytenoids will tilt anteriorly, downward, and medially, and (3) the true vocal folds will close. With the airway protected, the bolus can pass safely through the pharynx. Timely hyolaryngeal excursion is important relative to the timing of upper esophageal sphincter (UES) opening as well [6]. Three physiologic events have to occur for successful UES opening. First, vagal firing to the UES must cease. Second, the hyolaryngeal complex must elevate and move anteriorly. Third, bolus pressure must be sufficient to maximize UES opening. When all forces are acting as appropriate and the hyoid is at its maximum displacement, the cricopharyngeus muscle is pulled open maximally, allowing passage of the bolus into the upper esophagus. If the timing is not

synchronized with bolus flow, the bolus will not completely enter the upper esophagus and residue will remain in the pyriform sinuses.

Based on what is known about the simultaneous and sequential dynamics of the oral and pharyngeal stages, a timely initiation of the pharyngeal swallow in relation to the end of the oral stage is also essential. The transition between the oral stage of swallowing and the pharyngeal stage of swallowing has been defined differently by researchers. Logemann [6] stated that it "begins when the bolus head reaches the point where the lower edge of the mandible crosses the tongue base and ends when laryngeal elevation begins in the context of the rest of the swallow" (p. 77). The time that passes between those two events was defined as Pharyngeal Delay Time (PDT). In a study of individuals without swallowing problems, pharyngeal delay time was less than 1 s for all volumes of 1, 5, 10 and 20 ml [2,4–6]. Older subjects had significantly longer pharyngeal delay times than the younger subjects. Normal subjects over 60 years old had delay times of 0.4–0.5 s, while normal subjects under 60 years old had delay times of 0–0.2 s.

Robbins et al. [1] defined the transition between the oral and pharyngeal stages differently. Stage Transition Duration (STD) was defined as the time between barium first passing the ramus of the mandible until the beginning of maximum hyoid excursion, which is the initiation of superior–anterior hyoid movement. In other words, rather than focusing on the first sign of *laryngeal* movement within the context of the swallow, Robbins et al. proposed that it begins with the first sign of superior–anterior *hyoid* movement. Stage transition duration was also observed to increase with age. The initiation of maximal hyoid excursion occurred for younger normal subjects before the bolus passed the ramus of the mandible, and for older participants it occurred after the bolus passed the ramus. The main difference between PDT and STD is that PDT marks from the movement of the thyroid cartilage, and STD marks from the superior–anterior movement of the hyoid.

In 1994, Perlman et al. [7] reported a measure of delayed onset of swallowing that was easier to visualize and less dependent on a 100-ms clock. Specifically, Delayed Pharyngeal Swallow (DPS) was reported to occur when laryngeal elevation is not triggered within 1 s of barium entering the valleculae. As part of their study [7], they scaled the severity of the delay: greater than 1 s was considered a mild delay; between 1 and 2 s was considered a moderate delay, and greater than 5 s constituted what was considered to be a severe delay [7]. Since that time our understanding of the complexities of pharyngeal onset of swallowing has definitely changed. Nonetheless, this 1994 measure is still closer to how clinicians actually look at delayed onset of swallowing in practice. Most clinicians do not have 100-ms timers and use more gross visual estimates to make this rating. Thus, its relevance should not be discounted without due accord.

A prolonged transition between the end of the oral stage and the beginning of the pharyngeal stage, or the initiation of the pharyngeal swallow, has been linked to aspiration. Aspiration has been defined as the entry of food or liquid into the airway below the true vocal folds [6]. In the study by Perlman et al. [7], aspiration occurred more frequently in patients with moderate to severe DPS (53%–56%) than with mild DPS (42%). A more recent study also linked delayed swallowing, as defined by prolonged STD, and the occurrence of aspiration [8]. Aspiration of food or liquid when swallowing has been associated with the development of aspiration pneumonia [9]. Thus, while many other factors may also contribute to a negative health outcome such as aspiration pneumonia [10], the presence of a delayed initiation of the pharyngeal stage of swallowing (by causing aspiration) can be considered one such factor. Treatments to reduce the time between the oral and pharyngeal stages have been investigated [11,12]. With at least three definitions of this transition between stages, however, it is not evident which one is most valuable for differentially diagnosing a normal vs. abnormal stage transition. Normative data have been collected for PDT [2,4,5] and STD [1]. To our knowledge, however, no studies have examined normative data for all of these published measures together with normal participants. Oropharyngeal swallowing onset is more complex than one measure can espouse to. Nonetheless, this study is a simple effort to examine and compare a few of the measures of delayed onset of swallowing in the literature.

The purpose of this investigation was to examine the temporal differences (means and standard deviations in seconds) among three measures of pharyngeal stage transition in 40 normal participants. All three measures of transition duration were analyzed and reported. Age and gender differences were compared. Our specific research questions were as follows: (1) Which measures of pharyngeal swallow onset (if any) are most sensitive to normal aging? and (2) Which measures of pharyngeal swallow onset (if any) are most sensitive to differences in gender?

Methods

Participants

Videotapes of videofluoroscopic swallowing examinations (VFSE) for 40 normal individuals of varying ages and genders were analyzed using the three definitions of transition between the oral and pharyngeal stages. VFSE data were analyzed from preexisting videotapes obtained from a prior investigation [3]. All subjects in that investigation were screened for neurologic or structural abnormalities which would interfere with swallowing. Each subject completed a comprehensive questionnaire and passed a cranial nerve examination and an oral motor/structural examination before participation. Individuals with any neurologic or structural abnormality affecting the head and neck were excluded. Individuals were divided into two age groups based on previous studies revealing age and gender differences for individual measures of stage transition [1,2,4,5]. Thus, tapes were analyzed for 20 individuals between the ages of 21 and 51 and for 20 individuals between the ages of 70 and 87. Ten men and ten women were in each group.

In each VFSE, the subject was seated upright in a stretcher chair for the duration of the study. VFSEs were conducted with a mobile, C-arm X-ray (OEC Diagnostics, Model 9400) system. Each study was recorded with a Panasonic Super-VHS PV-S7670 Pro Line Multiplex videocassette recorder with an attached 100-ms digital videotimer (TEL Video Products model VC 436). Participants were seated and viewed radiographically in the lateral plane. The fluoroscopic tube was focused on the oral cavity from the lips anteriorly to the pharyngeal wall posteriorly, and from the nasopharynx superiorly to just below the UES area. The subjects each swallowed two 5-ml and then two 10-ml thin-liquid boluses (50/50 mixture of E-Z-HD Barium Sulfate Powder for Suspension). Additional swallows of puree and solid consistencies were recorded but were not analyzed for this study.

Procedures and Statistics

To answer the proposed research questions, the principal investigator reviewed each videotape and analyzed 5-ml and 10-ml thin-liquid swallows using slow-motion frame-by-frame analysis. Only thin liquids were analyzed because thin liquids are the primary concern for individuals with delayed transitions between the oral and pharyngeal stages. The measurements followed the three published measures for transition between the oral and pharyngeal stages:

(1) Pharyngeal Delay Time (PDT): The time from bolus head passing the posterior edge of the ramus of the mandible until the initial observation of laryngeal elevation [2,4,5]. Initial laryngeal elevation time was recorded by observing the most superior-anterior edge of the thyroid cartilage. Typically, some calcification helps in the localization of this area. The first superior movement of the thyroid cartilage that actually results in a swallow was recorded. Any up and down movements of the larynx before the onset of the swallow were ignored.

(2) Stage Transition Duration (STD): The time from bolus passing the posterior edge of the ramus of the mandible until maximal excursion of the hyoid is initiated [1]. The initiation of maximal excursion of the hyoid was recorded as the first anterior–superior hyoid movement that results in an actual swallow event. During this time, the hyoid begins to blur as it moves more quickly than the recording can capture. Up and down movements of the hyoid that did not result in a swallow were ignored.

(3) Delayed Pharyngeal Swallow (DPS): The time from the head of the bolus reaching the valleculae to the initiation of laryngeal movement [7]. Perlman et al. did not specifically define how they rated the bolus entering the valleculae. For this study we used the methodology used with the other measures for the head of the bolus movement. Trickle down barium was not counted in this measure. Rather, the tongue must have been actively pushing the barium into the pharynx for the first part of this measure to be counted. The bolus head was considered to have reached the valleculae when it passed below and anterior to the tip of the upright epiglottis. Thus, if you drew a straight line from the tip of the epiglottis at rest back to the base of tongue, you would mark the top of the valleculae for this measure. Initiation of laryngeal movement was defined exactly as it was for PDT.

First, all liquid swallows were analyzed for the following points of occurrence with the 100-ms timer: (1) bolus head passing the ramus of mandible, (2) bolus passing the ramus of mandible, (3) entrance of the bolus into the valleculae at the level of the tip of the upright epiglottis, (4) beginning of laryngeal elevation, and (5) initiation of maximum hyoid elevation.

Second, times for each of the above-mentioned markers were recorded and used to calculate the three measures of stage transition, i.e., PDT = initiation of laryngeal elevation (4) - bolus head passing into the ramus of mandible (1), STD = initiation of maximum hyoid elevation (5) - bolus passing the ramus of mandible (2), and DPS = beginning of laryngeal elevation (4) - bolus entrance into valleculae (3).

Age and gender differences were analyzed using a repeated-measures one-way analysis of variance (ANOVA) with one repeated factor, volume of bolus, and two between-subject factors, age and gender. Wilkin's lambda was used to determine the significance ($p < 0.05$).

Results

None of the subjects, according to our analyses of the videotapes, were observed to have overt signs of dysphagia. No aspiration was observed. No residue other than trace coating was observed. All swallows appeared to be complete and all physiologic aspects of the swallow, including tongue base retraction, epiglottic inversion and seal, and UES opening, appeared to be clinically normal.

Reliability

For intrajudge reliability, the investigator randomly selected and reanalyzed 10% of the patients' VFSE tapes. A significant correlation between the first and second ratings was observed ($r = 0.88$, $p < 0.01$). For interjudge reliability, a second judge analyzed 10% of the patients' videotapes. The second judge was a certified speech pathologist who evaluates patients for dysphagia on a regular basis and who had undergone training on VFSE temporal measures for another investigation. Results were compared with the results of the primary investigator. Significant

Table 1. Mean and standard deviation (SD) by age group in three pharyngeal swallowing measurements

		Younger ($n = 20$)			Older ($n = 20$)		
Duration measures (s)	Volume (ml)	Mean	SD	Range	Mean	SD	Range
PDT	5	)0.10	0.05	0.26	0.17	0.05	0.29
	10	)0.10	0.06	0.21	0.19	0.05	0.17
STD	5	)0.06	0.07	0.20	0.20	0.06	0.26
	10	)0.08	0.07	0.26	0.23	0.07	0.24
DPS	5	)0.13	0.17	0.50	0.06	0.09	0.34
	10	)0.18	0.08	0.31	0.01	0.05	0.20

PDT - pharyngeal delay time, STD - stage transition duration, DPS - delayed pharyngeal swallow.

correlations between judges were observed (r = 0.83, $p < 0.01$).

Age Effects

Means and standard deviations (SD) for the three transition duration measurements, separated into the age categories for the younger and older subjects, are presented in Table 1. A boxplot of age differences in the three transition duration measurements is provided in Figure 1.

Both Pharyngeal Delay Time (PDT) [$F(1,36) = 4.56$, $p = 0.4$] and Stage Transition Duration (STD) [$F(1,36) = 7.28$, $p = 0.01$] were significantly different between younger and older subjects. When measuring PDT, the laryngeal elevation of older subjects typically began after the head of bolus reached the ramus of the mandible in both volume sizes, whereas laryngeal elevation in younger subjects occurred before the head of bolus reached the ramus. When measuring STD, the same was true. Maximum hyoid excursion was initiated before the bolus reached the ramus of the mandible in younger subjects and after the bolus passed the ramus of the mandible in older subjects. For Delayed Pharyngeal Swallowing (DPS), however, there was no significant difference between younger and older subjects [$F(1,$
$36) = 2.82$, $p = 0.10$], despite the fact that mean times were longer for older subjects than for younger subjects.

Gender Differences

Means and standard deviations (SD) for the three transition duration measurements broken down by gender are presented in Table 2. A boxplot of gender differences in the three transition duration measurements is provided in Figure 2. No significant gender differences were observed across the three measures of pharyngeal delay. When measuring pharyngeal delay with PDT, mean durations were longer for women than for men on both 5-ml and 10-ml boluses, but the differences were not significant. When using STD, no such trend was observed. Women had longer STDs for 10 ml, and men had longer STDs for 5 ml. Mean durations using DPS were the exact opposite. Women's DPSs were longer for 5-ml boluses, but men's DPSs were longer for 10-ml boluses.

Discussion

Age

The results of this investigation support previous investigations regarding age differences for Pharyngeal Delay Time (PDT) and Stage Transition Duration (STD) in normal populations [1,2,4,5]. Younger subjects tend to initiate both laryngeal movement and hyoid excursion before the point when the head of the bolus reaches the ramus of the mandible. As people get older, laryngeal elevation and initiation of maximum hyoid excursion may be delayed because of changes in motor and sensory functions [13,14]. Timely hyolaryngeal elevation is important for two reasons: (1) epiglottic tilt and seal help to prevent premature spillage of material into the laryngeal vestibule prior to swallow initiation, and (2) timely opening of the UES allows continuous bolus movement through the pharynx into the esophagus. Normal older subjects have been observed to have increased laryngeal penetration for liquid boluses when compared with normal younger subjects. However, no increase in aspiration has been reported. The increase in penetration may well be the result of the longer delay in the initiation of the pharyngeal swallow. Likewise, a slight increase in pyriform residue has been observed for older versus younger subjects [6]. While this, as well, may be attributable to delayed hyolaryngeal excursion and subsequent de-

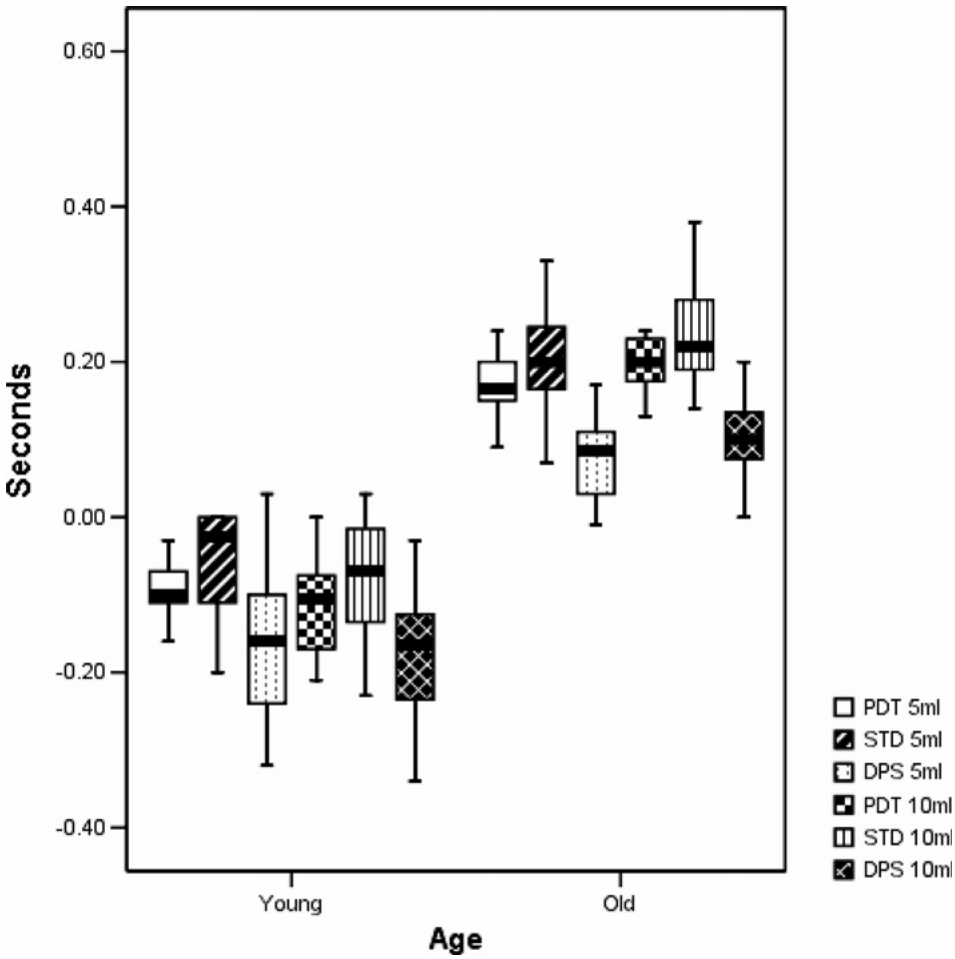

Fig. 1. A boxplot of age differences in three pharyngeal swallowing measurements: PDT - Pharyngeal Delay Time, STD - Stage Transition Duration, DPS - Delayed Pharyngeal Swallow. The "box" in a boxplot shows the median as a line, 25th percentile and 75th percentile of the distribution of the box. The "whiskers" represent the largest and smallest observed scores.

Table 2. Mean and standard deviation (SD) by gender differences in three pharyngeal swallowing measurements

		Men ($n = 20$)			Women ($n = 20$)		
Duration measures (s)	Volume (ml)	Mean	SD	Range	Mean	SD	Range
PDT	5	0.03	0.14	0.42	0.05	0.15	0.51
	10	0.04	0.18	0.44	0.05	0.16	0.44
STD	5	0.06	0.14	0.47	0.01	0.15	0.51
	10	0.06	0.19	0.61	0.09	0.16	0.54
DPS	5	0.02	0.19	0.64	0.05	0.15	0.43
	10	0.05	0.16	0.51	0.02	0.14	0.46

PDT - pharyngeal delay time, STD - stage transition duration, DPS - delayed pharyngeal swallow.

lays in UES opening, no substantive problems have been reported in older normal individuals. In addition, any effects on UES function are multifaceted and must be examined from different perspectives. UES function is affected not only by hyolaryngeal excursion but also neural relaxation of the sphincter and bolus propulsion.

Regardless of the direct results, the effects of aging are evident. Reasons provided vary and may be multifaceted. Robbins et al. [15] affirmed that maximal lingual pressures decline with age and cited many possible reasons. Among these were reduced muscle mass [16], changes in fiber density [17], and reduced numbers of functional motor units [16]. It has also been suggested that some mechanism of the central nervous system may be less able to distinguish a distinct signal from noise in the system [18]. Thus, increased sensory input may be required to stimulate

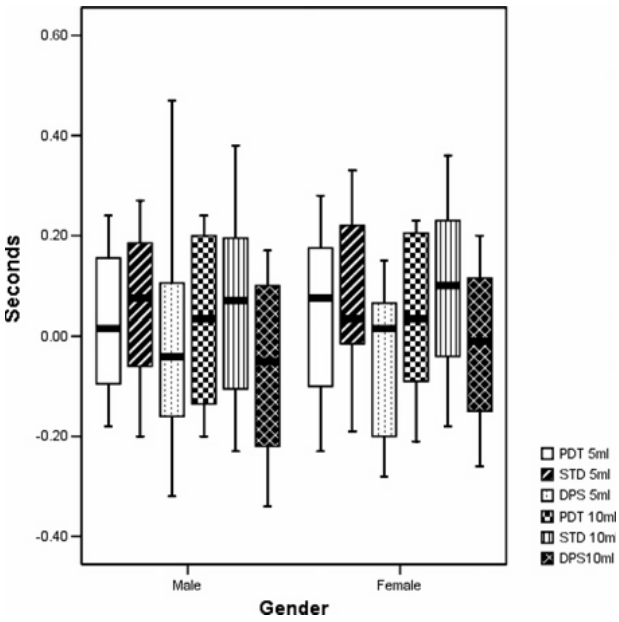

Fig. 2. A boxplot of gender differences in three pharyngeal swallowing measurements: PDT - Pharyngeal Delay Time, STD - Stage Transition Duration, DPS - Delayed Pharyngeal Swallow.

the appropriate response. We cannot even be certain that the delays that occur with age for hyoid and laryngeal movement are negative. Some changes in the swallowing mechanism may be natural compensations for changes in motor and sensory function. Thus, delayed onset of the swallow may be adaptive. It has been suggested that the duration of UES opening may be extended before and after the bolus reaches the UES for older populations as bolus propulsive forces decline. Studies by Robbins et al. [1] and Logemann et al. [4,5] support the idea that older populations have longer UES opening durations than younger populations. Such speculations are neither supported nor negated by the current data. Instead, this article examines the age and gender differences for this one temporal aspect of the swallow based on three definitions.

Based on these data, it appears that STD and PDT are both sensitive to changes that occur with age. One point to be underscored is that even though DPS revealed no *significant* differences between younger and older normal subjects, that younger subjects on the whole had negative values for DPS (the initiation of laryngeal elevation occurred before the bolus reached the valleculae) and older subjects had positive values for DPS (the initiation of laryngeal elevation occurred after the bolus reached the valleculae). Thus, differences exist. Moreover, DPS was originally developed to differentiate between disordered and normal swallowing, not between normal old and normal young swallowing. According to Perlman et al. [7], it did that. DPS was significantly longer for disordered subjects than normal controls. What these results do indicate is that STD and PTD are more sensitive to the effects of normal aging. Additional research should address comparisons among the three measures for distinguishing normal versus abnormal swallowing function. Such research should focus on aspiration of thin liquids before and/or during the swallow, as this would be the most likely pathology resulting from delayed initiation of the pharyngeal swallow.

Gender

Measurements of PDT, STD, and DPS produced no significant differences for men versus women in this study. Robbins et al. [1] and Logemann et al. [5] reported significant differences in duration of UES opening between men and women and speculated that prolonged opening of the UES in women resulted as a compensation for smaller head and neck anatomy. Regardless, no effects of gender on initiation of the pharyngeal swallow have been reported.

Clinical Importance

Research regarding the biomechanical measurements of swallowing helps clinicians develop management and treatment plans specific to the type of swallowing problem. Triggering of the pharyngeal swallow induces several related physiologic activities: (1) velopharyngeal closure to the posterior pharyngeal wall to seal the nasopharynx and prevent food or liquid from entering the nasopharynx, (2) elevation and anterior movement of the hyoid and larynx which contribute to epiglottic closure and opening of the UES, (3) closure of the larynx to protect the airway from penetration or aspiration of the bolus, and (4) opening of the cricopharyngeal sphincter to allow passage of the bolus into the esophagus [19]. Thus, delays in the triggering of the pharyngeal swallow can create problems in any or all of the above-mentioned areas. Normative data for many temporal measures have been obtained and reported [1–5]. This study showed that the prolongations in the timing of the pharyngeal swallow exist for older individuals compared with younger individuals. However, ''how long is too long'' has not yet been determined. In addition, this study has several limitations, including a relatively small number of subjects and VFSE data derived from a previous investigation. Future research should evaluate these measures for their ability to distinguish between aspirators and nonaspirators in patients with dysphagia.

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