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Biomechanical and Temporal Measurement of Pharyngeal Swallowing for Stroke Patients with Aspiration

Youngsun Kim
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a dissertation written by Youngsun Kim entitled "Biomechanical and Temporal Measurement of Pharyngeal Swallowing for Stroke Patients with Aspiration." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Speech and Hearing Science.

Carl W. Asp, Major Professor

We have read this dissertation and recommend its acceptance:

Isa Schwarz, Molly Erickson, Olga Welch

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Vice Chancellor
And Dean of the Graduate Studies

Biomechanical and Temporal Measurement of Pharyngeal Swallowing for Stroke Patients with Aspiration

A Dissertation

Presented for the Doctor of Philosophy Degree

The University of Tennessee, Knoxville

Youngsun Kim

May 2004

DEDICATION

사랑하는 어머니께 바칩니다

Person of My Life: My Mom 'Yangsoon Lee'

And

Person of My Career: My Advisor 'Carl W. Asp'

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ABSTRACT

This study compared three pharyngeal swallowing measurements: Pharyngeal Delay Time (PDT), Stage Transition Duration (STD), and Delayed Pharyngeal Swallow (DPS) on the correct classification of three groups of subjects. These groups were: 15 stroke patients who aspirated (aspirators), 15 stroke patients who did not aspirate (non-aspirators) and 15 normal subjects.

Overall, the STD had highest mean classification among the three pharyngeal swallowing measurements. All three measures has a significant difference between aspirators and normal subjects. None of the measurements showed a difference between non-aspirators and normal subjects. The aspirators and the normal subjects were classified correctly most often; whereas the non-aspirators were considerably lower. The aspirators had the longest duration for triggering pharyngeal swallowing, whereas non-aspirators and normal subjects had similar durations. Clinical implications were discussed.

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CHAPTER I

INTRODUCTION

Dysphagia is a disorder of feeding or swallowing. In adults, it usually involves structural damage to the oropharynx or damage to the neurosensory/neuromotor pathways, both of which affect the oropharyngeal function. Stroke is a common cause of dysphagia. It causes both feeding and swallowing disorder between the oral cavity and the lower esophageal sphincter. Some patients with dysphagia have aspiration, which is the entry of food and/or liquid into the airway during the swallowing (Martin et al., 1994).

Aspiration is often a precursor to aspiration pneumonia (Crausaz and Favez, 1988). In fact, forty-three percent of hospitalized elderly patients have aspiration pneumonia; it is one of the leading causes of death in this population (Langmore, et al, 1998). In addition, stroke patients with aspiration may have nutritional problems, i.e., such as dehydration, malnutrition, and weight loss (Logemann, 1998).

Oropharyngeal swallowing is divided into three stages, i.e., oral preparatory, oral, and pharyngeal. In normal swallowing, the bolus is propelled from the oral cavity into the pharyngeal cavity. Then, the pharyngeal swallow is triggered. Triggering of the pharyngeal swallow results in the elevation of the hyolaryngeal structure to close the laryngeal vestibule at the three levels (Logemann, 1998): These levels are: 1) the epiglottis closes over the arytenoid cartilages; 2) the false vocal folds close, while the arytenoids tilt posteriorly; and

3) the true vocal folds close. The hyolaryngeal elevation assists the laryngeal closure, which protects the airway; it also assists the opening of upper esophageal sphincter (UES). This opening allows the bolus to pass easily into the esophagus (Logemann, 1998). When the hyoid is at its maximum excursion, the cricopharyngeus muscle is pulled open maximally, allowing the bolus to safely pass through. If these events are not synchronized, the flow of the bolus is disrupted. For example, if the bolus enters the pharynx prior to the closing of the laryngeal vestibule, aspiration usually occurs before the swallowing. Likewise, if the bolus entering the pharynx is delayed or the hyolaryngeal excursion is insufficient to open the UES, the bolus does not pass into the esophagus. Then, these residue from the bolus remains in the pyriform sinuses; this produces aspiration after swallowing.

The bolus passage from the oropharynx into the hyopharynx is referred to as the 'stage transition' (Robbins et al., 1992). Since the changes in pharynx occur prior to the bolus passing into the pharynx, a delay in triggering is described as a prolonged stage transition. This delay leaves the airway open, which increases the risk of aspiration. These pharyngeal changes are necessary.

Researchers have reported three measures of the stage transition of swallowing. The first measurement is the time between the head of the bolus passing the lower edge (ramus) of the mandible and the initiation of laryngeal elevation; it is the 'Pharyngeal Delay Time (PDT)'. With normal swallowing, the PDT is less than 1 second for bolus volumes of 1, 5, 10 and 20 ml (Tracy et al.,

1989, Logemann, et. al., 2000 and 2002). For older subjects (60 years and older), the PDT was 0.4 to 0.5 seconds, whereas younger subjects (under 60 years) were 0 to 0.2 seconds. Younger subjects had faster triggering of pharyngeal swallowing.

The second measurement is the duration between the oral and pharyngeal stages; it is the 'Stage Transition Duration (STD)' (Robbins, et. al., 1992). The STD is the time between the bolus passing the ramus of the mandible and the beginning of maximum hyoid excursion. As with the PDT, STD increases as age increases. For the younger adults, hyoid excursion occurred before the bolus passes the mandible, whereas for the older adults, it occurs after it passes the mandible.

The third measurement is the time between the bolus reaching the valleculae and initial laryngeal movement; it is the 'Delayed Pharyngeal Swallow (DPS)' (Perlman, et al., 1994). Perlman, et al. (1994) scaled the severity of the delay as mild (between 1 and 2 seconds), moderate (between 2 and 5 seconds), and severe delay (greater than 5 seconds). Aspiration was more frequently (53%-56%) in the patients with moderate to severe delays, whereas it was less frequent (42%) for mild delays.

Currently, there are data on normal subjects for the PDT (Tracy et al., 1989, Logemann, et. al., 2000 and 2002), for the STD (Robbins et al., 1992), and on dysphagia patients for the DPS (Perlman, et al., 1994). Kim, et al (2003) used normal young and older subjects to compare three measurements. The current

study compared three groups; stroke patients with aspiration, stroke patients without aspiration, and normal subjects on these three measurements.

1. Purpose

The purpose of this study was to compare three pharyngeal swallowing measurements: Pharyngeal Delay Time (PDT), Stage Transition Duration (STD), and Delayed Pharyngeal Swallow (DPS) to determine which measure correctly classified: stroke patients who aspirated (aspirators), stroke patients who did not aspirate (non-aspirators) and normal subjects.

2. Research Questions

The following questions were addressed:

1) Does pharyngeal delay time (PDT) differentiate aspirators, non-aspirators and the normal subjects?

2) Dose stage transition duration (STD) differentiate aspirators, non-aspirators and the normal subjects?

3) Dose delayed pharyngeal swallow (DPS) differentiate aspirators, non-aspirators and the normal subjects?

CHAPTER II

REVIEW OF LITERATURE

1. Normal Oropharyngeal Swallowing Function

The purpose of swallowing is to safely transport food from the mouth to the stomach. Swallowing can be divided into three stages, corresponding to the normal swallowing physiology: oral, pharyngeal and esophageal (Logemann, 1998). The oral stage has been further broken down into two phases: oral preparatory and oral. Both of these phases are under voluntary neuromuscular control. The pharyngeal stage is partially under volitional control but is mostly reflexively. The esophageal stage is under involuntary neuromuscular control.

The oral preparatory phase begins when food is placed in the mouth. The lips, teeth, tongue and cheeks manipulate the food and reduce the consistency to a bolus ready to swallow. The sensory information from the bolus contributes to the oral preparatory stage. The shape and volume of the bolus is processed from sensory receptors in the oral cavity (Logemann, 1998). This sensory input will also assist in the elicitation of the pharyngeal swallow. During the oral preparatory phase, the pharynx and larynx are at rest.

The oral phase begins with posterior movement of the bolus and continues until the pharyngeal swallow is triggered. It requires complete labial and buccal musculature seal to prevent the bolus from leaking out of the oral cavity. In addition, proper tongue movement is required to propel the bolus posteriorly. Sufficient lingual pressures are necessary to force the bolus into the pharynx for

successful pharyngeal clearance. The oral stage of swallowing takes less than 1 second to complete (Logemann, 1998).

As a bolus is propelled from the oral cavity into the pharyngeal cavity, the pharyngeal swallow should be triggered. The sensory receptors in the oropharynx (a large portion of which reside in the anterior faucial pillars) and tongue send sensory information to the cortex and brainstem. It is hypothesized that the medullary swallowing center, comprised largely of the nucleus tractus solitarus and the ventromedial reticular formation, decodes the incoming sensory information and identifies the swallow stimulus. This information is sent to the nucleus ambiguous, as well as other motor nuclei relating to lingual function and hyolaryngeal excursion, to initiate the pharyngeal swallow (Miller, 1972). Triggering of the pharyngeal swallow means that the hyolaryngeal complex will begin to rise and the laryngeal vestibule will close at three levels (Logemann, 1998). These levels are: 1) the epiglottis will close over the arytenoid cartilages; 2) the false vocal folds will close and the arytenoids will tilt posteriorly; and 3) the true vocal folds will close. With the airway protected, the bolus passes safely through the pharynx. The pharyngeal triggering of the swallow results in several physiological activities. These are: 1) velopharyngeal apposition to the posterior pharyngeal wall to seal the nasopharynx and prevent food or liquid from entering the nasopharynx; 2) the elevation and anterior movement of hyoid and larynx which contribute to epiglottic closure and the opening of the UES; 3) the closure of 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 (Cook, et al., 1989).

2. Definitions for Transition Between Stages

The transition from the oral stage into the pharyngeal stage of swallowing has been measured differently by different investigators. Logemann (1989, 1998, 2000 and 2002) measured the end of the oral stage as the time when the head of the bolus passes the lower edge (ramus) of the mandible. The initiation of the pharyngeal swallow was defined as the first sign of laryngeal elevation. The time that passes between those two events (bolus crossing ramus of mandible and first sign of laryngeal elevation) was referred to as "Pharyngeal Delay Time (PDT)." For individuals without swallowing problems, PDT time was less than 1 second for all volumes (1, 5, 10 and 20 ml) (Tracy, et al., 1989). Older subjects had significantly longer pharyngeal delay times than the younger subjects. For normal subjects over age 60, the delay time was 0.4 to .5 seconds and for the younger subjects under aged 60, it was 0 to 0.2 seconds (Tracy, et al., 1989; Logemann et. al., 2000 and 2002).

Robbins and her colleagues (1992) measured the transition between the oral and pharyngeal stages differently. The end of the oral stage (Robbins et al., 1992) has been defined two ways. The first, similar to Logemann (1989 and 1998), is the time when the head of the bolus passes the ramus of the mandible. The second definition (Robbins, 1992) states that the oral stage ends when any

barium passes the ramus of the mandible. The initiation of the pharyngeal phase was defined as the time when the hyoid begins its anterior excursion. Thus, Robbins and colleagues (1992) have created the definition for the transition between the oral and pharyngeal stages. Stage Transition Duration (STD) was the time from first barium passing the ramus of the mandible until the beginning of maximum hyoid excursion. STD was increased with age (Robbins et al., 1992). The initiation of the maximal hyoid excursion occurred for younger normal subjects before the bolus passed the ramus of the mandible and, for older participants, after the bolus passed the ramus of mandible. A gradual increase of stage transition duration from negative to positive values has been shown to correspond with increasing age (Robbins et al., 1992).

Perlman, et al.(1994) measured the transition between the oral and pharyngeal phases differently and defined to the measure as delayed pharyngeal swallow (DPS). They stated that the swallow was delayed when the swallow did not trigger within 1 second after barium entered the valleculae. In addition, they scaled the severity of the delay: greater than 1 and less than 2 seconds was considered a mild delay; greater than 2 and less than 5 seconds was considered a moderate delay, and greater than 5 seconds was considered a severe delay.

3. Factors that affect the Transition between Oral and Pharyngeal Stages

As people get older, the transition between oral and pharyngeal stages tends to be longer (Tracy, et al., 1989; Robbins et al., 1992). Robbins and her colleagues (1992) reported that older subjects exhibit increases in stage transition duration due to a delay in initiation of maximal hyoid excursion. Despite longer STDs, older individuals were not likely to aspirate. Apparently, the older subjects were able to compensate for the delayed triggering of the pharyngeal swallow.

Bolus volume and consistency have been observed to affect the transition between oral and pharyngeal stages. In a study, it was observed that pharyngeal delay time increased as bolus volumes increased. However, this finding was not statistically significant (Tracy et al., 1989). In a similar study, semisolid boluses were correlated with significantly longer transitions than liquid boluses (Robbins et al., 1992). The increased transition duration may be related to the increased viscosity. This makes sense, as thicker boluses move more slowly through the pharynx.

4. Populations at Risk for Prolonged Transition between Oral and Pharyngeal Stages.

Between 30 and 50% of all individuals who suffer a stroke(s) from Cerebrovascular Accidents (CVAs) have swallowing problems (Logemann, 1998). Dysphagia resulting from a stroke(s) is considered a major cause of

respiratory complications, such as aspiration pneumonia, dehydration, and malnutrition (Logemann, 1998). A degree of aspiration may occur in normal, healthy adults without medical complications (Crausaz and Favez, 1988), e.g., Finegold (1995) reported that 50% of normal adults aspirate during sleep. However, aspiration in the patients with a stroke(s) may lead to serious medical consequences, such as bacterial pneumonia, chemical pneumonitis, or medical obstruction of the airways (Kirsch and Sanders, 1988).

Many stroke patients with dysphagia exhibit prolonged transitions between the oral and pharyngeal stages. Left CVA patients have been observed to have more deviant oral stage coordination with subsequent residue. Those with right CVA patients have been observed to have more problems with the timing of pharyngeal stage components and subsequent penetration/aspiration. Patients with other types of cerebrovascular disease, such as lateral medullary syndrome, may exhibit severe delays in the triggering of the pharyngeal swallow and with bilateral damage, have no swallow response at all (Robbins and Levine, 1988).

Other patients at risk for delays in transition between the oral and pharyngeal stages include those with disorders such as: traumatic brain injury (TBI); Parkinson disease; multiple sclerosis; Bulbar palsy; and head and neck cancer, etc. (Logemann, 1998). Perlman and her colleagues (1994) analyzed VFSE of the patients with dysphagia from a stroke(s), TBI, Parkinson disease, or head and neck cancer. They reported that adult dysphagic patients with these problems showed a prolonged transition between the end of the oral stage and the

beginning of the pharyngeal stage, or the initiation of the pharyngeal swallow, which have been linked to aspiration. In addition, the presence of a delayed initiation of the pharyngeal stage may be linked to important, negative health outcomes from aspiration.

5. Dysphagia Management/Treatment Options.

The major goals of dysphagia management/treatment are to establish optimal nutritional status, and to eliminate and reduce the risk of developing medical complications after the aspiration (Dippo, Holas, Reding, Mandel, and Lesser, 1994). The formalized multidisciplinary team approach including a speech pathologist, nursing staff and other related professionals is essential for successful dysphagia management. A team of professionals is able to conduct the swallowing evaluation, plan effective management and treatment, and monitor patient's prognosis objectively. In addition, the multidisciplinary team approach provides a positive influence for patients' nutritional status like weight and caloric intake (Martens, Cameron, and Simonsen, 1990).

Medical management, diet modification, and behavioral swallowing therapy, as a part of dysphagia management, should be considered depending on patient's nutritional status, hydration and oral feeding capacity (Buchholz, 1994). Medical management includes nonoral feeding techniques, surgical techniques to control the aspiration, and medications to improve specific swallowing problems. Nonoral feeding techniques are used for patients who cannot take nutrient and

water by mouth. These techniques include Nasogastric (NG) feeding, Percutaneous Endoscopic Gastrostomy (PEG) and Jejunostomy (Logemann, 1998). However, patients can still have gestroesophageal reflux and aspiration, even though those nonoral feeding techniques.

Diet modification strategy is used to determine the most appropriate method of nutritional support based on patient's weight and hydration status (Molseed, 1999). It includes the change of diet consistency. If the patient is capable of oral feeding, solid food modification, such as pureed and naturally soft food, and thickening the liquid should be considered. Thick liquids are often tolerated more safely than thin liquids in the patients with pharyngeal swallow delay (Martin, 1994). Thick liquid less likely to fall into the airway during the pharyngeal swallowing delay as compared with thin liquids. In addition, thick liquid may result in increased tongue movement to facilitate more timely initiation of the pharyngeal swallow, and be less likely to penetrate and aspirate the incomplete sealed larynx than a thin liquid

Behavioral therapy techniques include both compensatory and rehabilitative techniques. Compensatory techniques, such as the chin tuck and head turning, are employed to redirect food through the oral cavity and pharynx. Compensatory techniques cannot change the swallowing physiology, but are helpful in patients who are anticipated to recover oral intake later. However, diet modification and compensatory techniques did not show effectiveness to reduce the development of medical complications related to dysphagia. Patients who

used to these techniques did not demonstrate more independence in the use of these techniques after discharge from the hospital (Logemann, 1998). Instead, patient and family instruction for these techniques during inpatient management were as effective as a therapist oriented program.

Rehabilitative techniques, such as the hard swallow and Mendelsohn maneuver, may improve the muscle function through exercise (Logemann, 1995). Rehabilitative techniques are designed to change the swallowing physiology through exercises and effortful breath hold for vocal fold closures. The efficacy of Mendelsohn maneuver with dysphagia patients was demonstrated by significant reduction of the aspiration occurrence between the treated and untreated groups. Even for patients with a history of aspiration pneumonia, the rehabilitative treatment is an effective tool (Logemann, 1986).

A behavioral technique to improve triggering pharyngeal swallow have been investigated (Lazzara, et al., 1886). 23 of 25 stroke or head injury patients showed reduced transition duration after cold thermal application to anterior faucial arch. However, the carryover of stimulation was not established. Rosenbeck (1996) indicated that the thermal stimulation had a short term effect to reduce the transition duration for the dysphagia patients after stroke, but there were no substantial differences for the patients swallow recovery after undergoing routine application of thermal application compared with patients who did not receive.

In summary, individuals who suffer from stokes or other neurological

disease may develop swallowing problems. Aspiration is of great concern due to the potential for developing aspiration pneumonia, one of the leading causes of death in the elderly. It is essential to define normal biomechanics of swallowing in order to develop physiological profiles for individuals who are dysphagic. Aspiration of liquids often occurs prior to the onset of the pharyngeal swallow. Despite the establishment of several measures to define the onset of the swallow in relation to bolus movement, no data exist to differentiate potential aspirators based on such measures. Such work is clinically important due to the brevity of the modified barium swallow. Where aspiration may not be viewed on three swallows of liquid barium, a documented delayed onset of the swallow may help determine risk of aspiration and other health related complications after the x-ray is turned off.

CHAPTER III

METHOD

1. Subjects

A previous study videotaped an individual Videofluoroscopic Swallowing Exam (VFSE) on 60 stroke patients; 22 patients had aspiration and 38 did not have aspiration (McCullough, et, al., 1997). The 60 subjects' videotapes were loaned to the investigator of the current study. Then, he randomly selected 15 of the 22 patients with aspiration and 15 of the 38 patients without aspiration. Finally, he verified the independently the aspiration or non-aspiration for these 30 subjects. His evaluation agreed with the proven classification by McCullough, et al. (1997).

In addition, the current investigator analyzed the VFSE tapes of 40 normal subjects; 20 younger and 20 older subjects (Kim, et al., 2003). From Kim, et al (2003), the investigator randomly selected 15 of the 20 normal older subjects, who were age-matched other two groups. The age-matched groups had a mean age of over 70 years old (See Table 3-1). These 15 normal subjects served as a control group for comparison with stroke patient with aspiration or no aspiration.

For this experiment design, the 15 stoke patients with aspiration were of special interest, because aspiration is life threatening. The 15 stroke patients with no aspiration were included because less than 50% of them aspirate. This suggested that non-aspirators may have different swallowing patterns to compensate as a result of their stroke. The swallowing data of both groups may be

Table 3-1. The mean and standard deviation on age of the three subject groups

age

	N	Mean	Std. Deviation
aspirators	15	70.3333	5.82687
nonaspirators	15	69.8667	5.55321
normals	15	76.9333	4.58984

useful to develop diagnostic and treatment strategies.

2. Videofluoroscopic Swallowing Examination (VFSE)

As mentioned earlier, each subject was taped during a videofluoroscopic swallowing examination (VFSE). To accurately analyze the temporal sequence, a 100 ms videotimer and slow motion, frame-by-frame analysis was used the lateral plane. The fluoroscopic tube was focused on the oral cavity (the lips anteriorly to the pharyngeal wall posteriorly), and the nasopharynx (superiorly to just below the UES area). Each subject swallowed a 5ml bolus and a 10ml bolus of thin liquid. The bolus was a mixture of water and barium sulfate powder (McCullough, et. al, 2001).

3. Procedures of Biomechanical and Temporal Measurement

The current investigation focused on two types of biomechanics measures of swallowing: 1) the initiation of movement of the hyoid or the laryngeal structures, and 2) the bolus flow, including laryngeal aspiration.

The principal investigator examined the VFSE videotapes of the

aspirators, the non-aspirators, and the normal subjects for the liquid swallows. Thin liquids were used because they are the primary concern for individuals with delayed transitions between the oral and pharyngeal stages. Aspiration was the entry of the liquid below the true vocal folds (Logemann, 1998).

Three established pharyngeal transition measures were used in the current study. These were:

1) Pharyngeal Delay Time (PDT): The time from the bolus head passing the posterior edge of the ramus of the mandible until the initial laryngeal elevation (Tracy, et al., 1989, Logeman et al., 2000 and 2002).

2) Stage Transition Duration (STD): The time from the bolus passing the posterior edge of the ramus of the mandible until maximal excursion of the hyoid is initiated (Robbins, et al., 1992).

3) Delayed Pharyngeal Swallow (DPS): The time from the bolus reaching the valleculae to the initiation of laryngeal movement (Perlman, et al., 1994).

To calculate each measure, the following five reference points were observed: (1) head of the bolus into the pharynx, (2) bolus into the pharynx, (3) entrance of the bolus into the valleculae, (4) beginning of laryngeal elevation, and (5) initiation of maximum hyoid elevation (see Figure 3-1). For each subject, a worksheet was used to record these times in seconds for each point of occurrence (see Appendix A).

Then, the three pharyngeal measures were computed using these formula:

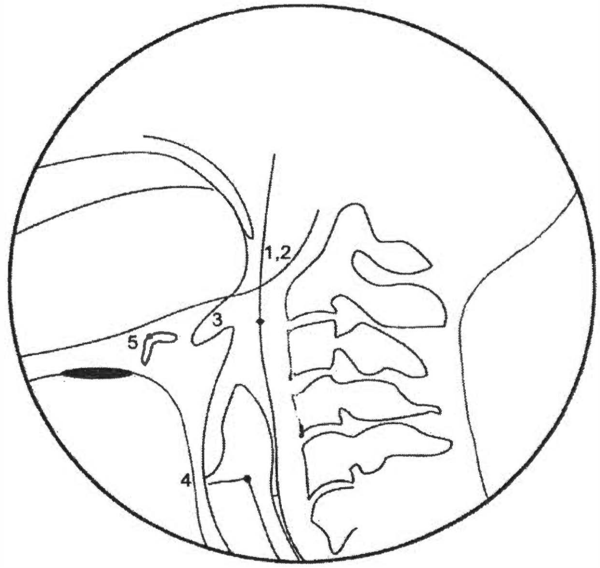

Figure 3-1. Tracing of lateral view from VFSE with five marked points of occurrence; 1. head of bolus, 2. bolus, 3. vallecule, 4. laryngeal elevation, 5. maximum hyoid excursion

PDT = initiation of laryngeal elevation (#4) minus the head of the bolus into pharynx (#1)

STD = initiation of maximum hyoid elevation (#5) minus the first sign of bolus into the pharynx (#2)

DPS = beginning of laryngeal elevation (#4) minus the bolus entrance into valleculae (#3).

Earlier, the investigator completed a comprehensive training procedure of timing measures in the swallowing. This training included 1) identification of the anatomy and physiology of the oropharyngeal structures of swallowing, 2) determination of aspiration, and 3) frame-by-frame analysis of VFSE.

4. Statistical Analysis

A separate Discriminant Analyses was completed for each measurement. Since this study had three groups and two volume sizes, two discrimination functions were performed. For example, among aspirators, non-aspirators, and normal subjects, if aspirators were different from the rest of groups, the first discriminant function separated aspirators from non-aspirators and normal subjects. Then, the second discriminant function compared non-aspirators and normal subjects. The Wilkin's Lamda was used to determine the significance of each function. The criterion of the significant level was set at $p<0.05$. Also, the discrimination functions predicted classification membership of each group. The classification results show both the percentage of correctly classified subjects and those that were misclassified (www.statsoftinc.com).

CHAPTER IV

RESULTS

1. Verification of Aspiration

As mentioned earlier, the forty-five subjects were classified as: 15 stroke patients with aspiration (aspirators), 15 stroke patients with no aspiration (non-aspirators), and 15 normal subjects with no aspiration (normal subjects). All of the 15 aspirators showed the entry of thin liquid into the airway below the true vocal folds.

No significant differences were observed between the 5ml and the 10ml of bolus volumes for the three duration measurements (see Appendix B). Thus, the data from the 5ml and the 10 ml were combined to simplify the reporting of means and standard deviations. As a result, the volume size was not considered a factor in this study.

2. Reliability

For inter-judge reliability, a second independent judge analyzed 5 randomly selected subjects (11%). The measurements of the investigator and second investigator were compared using Pearson Correlation Coefficient. A significant correlation was observed ($r= 0.92$, $p< 0.01$). For intra-judge reliability, the investigator re-analyzed these 5 subjects a second time. There was a significant correlation between the first and second measurements ($r=0.97$, $p<0.01$). Both intra- and inter-judge reliability were significantly correlated. This

investigation were considered reliable for this study.

3. Pharyngeal Duration Measurements

a. Pharyngeal Delay Time (PDT)

Table 4-1 and Figure 4-1 displays the mean and the standard deviation, and a boxplot for the three groups of subjects on the Pharyngeal Delay Time (PDT). For the aspirators, the laryngeal elevation began at 0.88 seconds after the head of bolus reached the ramus of the mandible, whereas for non-aspirator and the normal subjects, it occurred at 0.30 seconds and 0.18 seconds, respectively. The aspirators had slowest triggering of the pharyngeal swallow of thin liquid, whereas non-aspirators were similar to the normal subjects.

Discriminant Analysis showed that aspirators were significantly different from both the non-aspirators and the normal subjects ($p<0.01$) (see function 1 through 2 at Table 4-2 and Figure 4-2). However, non-aspirators and normal subjects were not significantly different from each other ($p=0.82$) on the PDT (see function 2 at Table 4-2). These data showed that non-aspirators had similar mean PDTs to normal subjects.

Table 4-3 displays the classification results on the PDT. Overall, 64.4% of the 45 subjects were classified correctly on the PDT. For the aspirators, 73.3% were correctly classified as aspirators, whereas 26.7% were classified as non-aspirators. For the non-aspirators, 33.3% were correctly classified as non-aspirators, whereas 46.7% were classified as normal subjects and 20% were

Table 4-1. The mean and the standard deviation (in seconds) of the three groups on the PDT

PDT

	N	Mean	Std. Deviation
aspirators	15	.8783	.53860
nonaspirators	15	.2997	.18049
normals	15	.1757	.02871

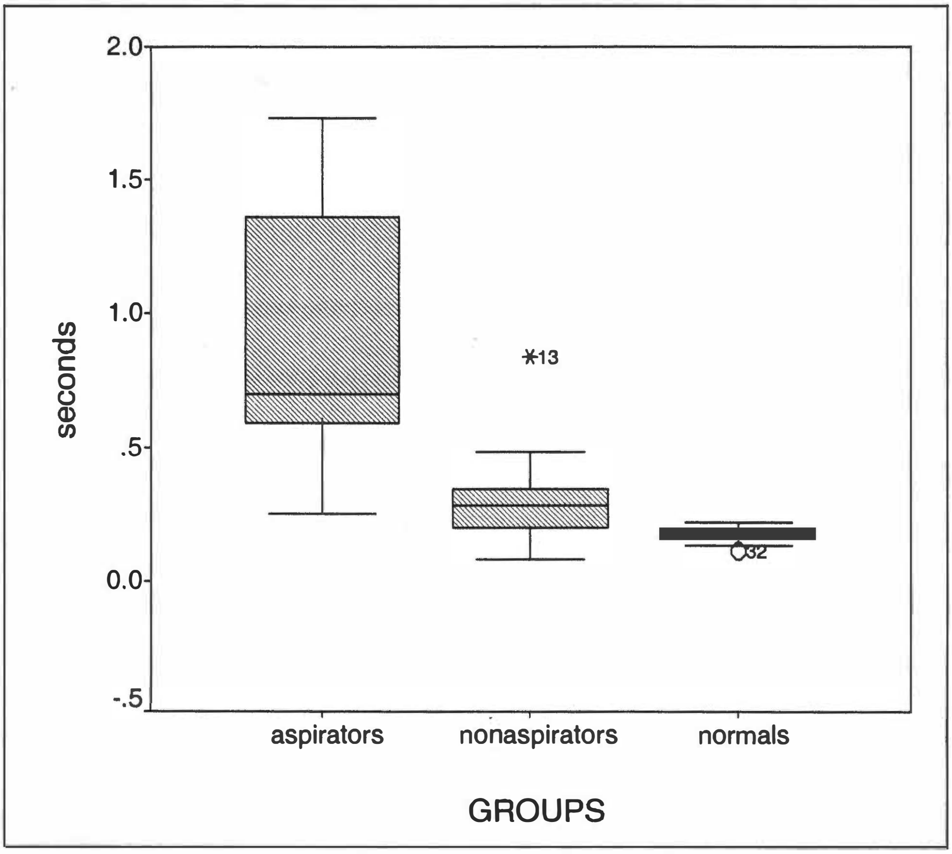

Figure 4-1. Boxplot (in seconds) of the three groups on the PDT

(The "box" in a boxplot shows the median score as a line and the first (25th percentile) and third quartile (75th percentile) of the score distribution as the lower and upper parts of the box, The "whiskers" shown above and below the boxes technically represent the largest and smallest observed scores that are less than 1.5 box lengths from the end of the box. On very rare occasions, scores are shown as open circles "o" or stars. These scores are ones that are, respectively "very rare". www.statsoftinc.com)

Table 4-2. The test of discrimination functions on the PDT

Test of Function(s)	Wilks' Lambda	df	Sig.
1 through 2	.428	4	.000
2	.999	1	.816

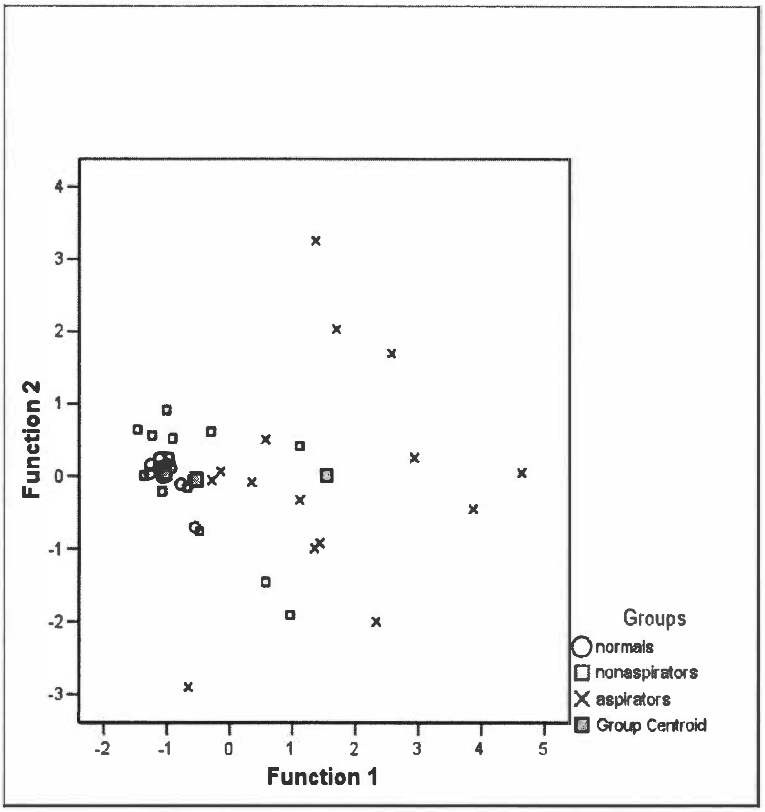

Figure 4-2. The discriminant functions on the PDT

Table 4-3. The classification results on the PDT

Classification Results [a]

			Predicted Group Membership			
		GROUPS	aspirators	nonaspirators	normals	Total
Original	%	aspirators	73.3	26.7	.0	100.0
		nonaspirators	20.0	33.3	46.7	100.0
		normals	.0	13.3	86.7	100.0

a. 64.4% of original grouped cases correctly classified.

classified as aspirators. For the normal subjects, 86.7% of normal subjects were correctly classified as normals, whereas 13.3% were classified as non-aspirator. None of normal subjects were classified as an aspirator. In summary, the aspirators and the normal subjects were correctly classified over 70% of the time, whereas the non-aspirators were correctly classified only 33.3% of the time. This suggests that the non-aspirators were near chance level for being classified as normal versus non-aspirating stroke patient.

b. Stage Transition Duration (STD)

Table 4-4 and Figure 4-3 displays the mean and the standard deviation, and a boxplot for the three subject groups on the Stage Transition Duration (STD). Similar to the PDT measurements, aspirators had the longest duration among three subject groups, non-aspirators as the second, and normals as the third. For the aspirators, the initiation of maximum hyoid excursion began at 0.98 second after the bolus reached the ramus of the mandible. For the non-aspirator and normal subjects, it occurred at 0.39 and 0.21 seconds, respectively. The results showed that aspirators had slowest triggering in pharyngeal swallow of thin liquid, whereas the non-aspirators and the normal subjects were similar in pharyngeal swallowing.

Table 4-4. The mean and the standard deviation (in seconds) of the three groups on the STD

STD

GROUPS	N	Mean	Std. Deviation
aspirators	15	.9830	.52892
nonaspirators	15	.3860	.19698
normals	15	.2110	.05795

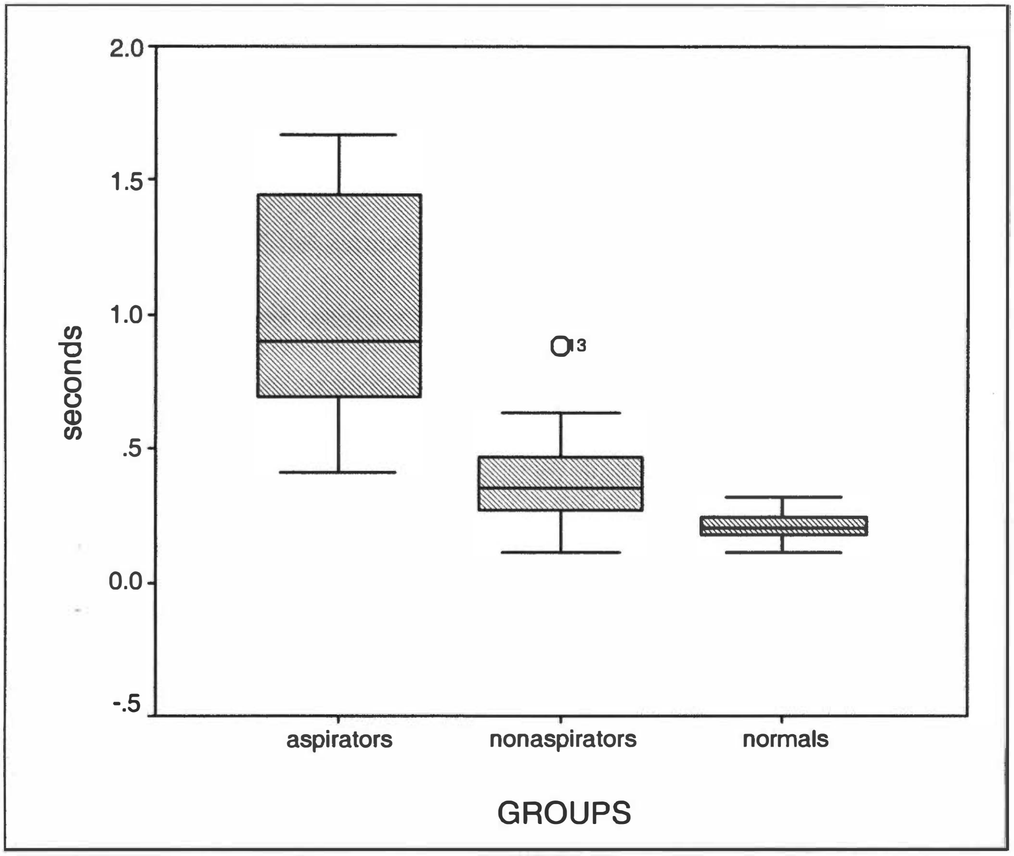

Figure 4-3. Boxplot (in seconds) of the three groups on the STD

Discriminant Analysis of STD had similar results to PDT. Aspirators were significantly different from both the non-aspirators and the normal subjects ($p<0.01$) (see function 1 through 2 at Table 4-5 and Figure 4-4). However, the non-aspirators and the normal subjects were not significantly different from each other ($p=0.73$) (see function 2 at Table 4-5). These data showed that that normal subjects and non-aspirators had similar mean duration of STD, even though non-aspirators were slower than normal subjects.

Table 4-6 displays the classification results on the STD. Overall, 71.1% of the 45 subjects were correctly classified. For the aspirators, 80% were correctly classified as aspirators, whereas 20% were as non-aspirators. For the non-aspirators, 40% were correctly classified, whereas 46.7% were classified as normal subjects and 13.3% were classified as aspirators. For the normal subjects, 93.3% were correctly classified, whereas only 6.7% were classified as non-aspirator. None of normal subjects was classified as an aspirator. In summary, the aspirators and the normal subjects were correctly classified over 80%, whereas only non-aspirators were correctly classified by 40% of the time. These results were similar to PDT measurements, even though STD had higher correct classification.

Table 4-5. The test of discrimination functions on the STD

Test of Function(s)	Wilks' Lambda	df	Sig.
1 through 2	.371	4	.000
2	.997	1	.731

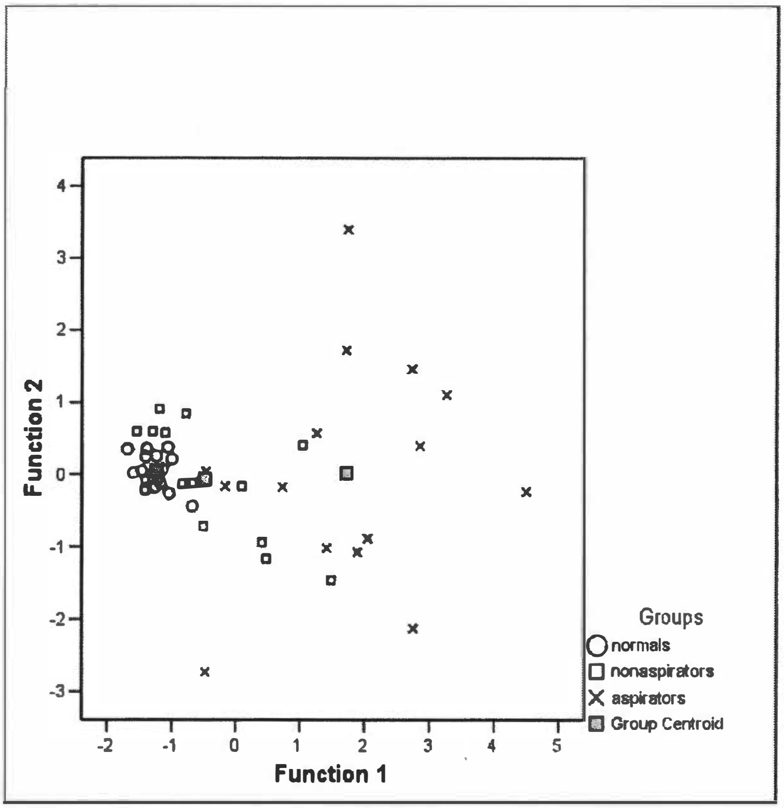

Figure 4-4. The discriminant functions on the STD

Table 4-6. The classification results on the STD

Classification Results[a]

		GROUPS	Predicted Group Membership: aspirators	nonaspirators	normals	Total
Original	%	aspirators	80.0	20.0	.0	100.0
		nonaspirators	13.3	40.0	46.7	100.0
		normals	.0	6.7	93.3	100.0

a. 71.1% of original grouped cases correctly classified.

c. Delayed Pharyngeal Swallow (DPS)

Table 4-7 and Figure 4-5 displays the mean and standard deviation, and a boxplot of the three subjects groups on the Delayed Pharyngeal Swallow (DPS). For the aspirators, the initiation of laryngeal elevation began at 0.73 second after the bolus reached vallecule. However, for the non-aspirator and normal subjects, the initiation of laryngeal elevation occurred at 0.14 and 0.08 seconds, respectively. This indicated that aspirators had slowest initiation of laryngeal elevation in pharyngeal swallow, as for the PDT and STD. However, non-aspirators and normal subjects had similar initiation of laryngeal elevation to normal subjects.

Discriminant Analysis of DPS showed similar results to PDS and STD. Aspirators were significantly different from both normal and non-aspirators ($p<0.01$) (see function 1 through 2 at Table 4-8 and Figure 4-6). However, non-aspirators and normal subjects were not significantly different from each other ($p=0.32$) (see function 2 at Table 4-8). The results indicated that normal subjects and non-aspirators had similar duration of DPS, even though the normal subjects had shorter duration than the non-aspirators.

In Table 4-9, the classification results of subjects were displayed for the DPS. Overall, 57.8% of the 45 subjects were correctly classified by DPS. For the aspirators, 73.3% were correctly classified as aspirators, whereas 26.7% were classified as non-aspirators.

Table 4-7. The mean and the standard deviation (in seconds) of the three groups on the DPS

DPS

	N	Mean	Std. Deviation
aspirators	15	.7287	.48806
nonaspirators	15	.1447	.18703
normals	15	.0757	.06285

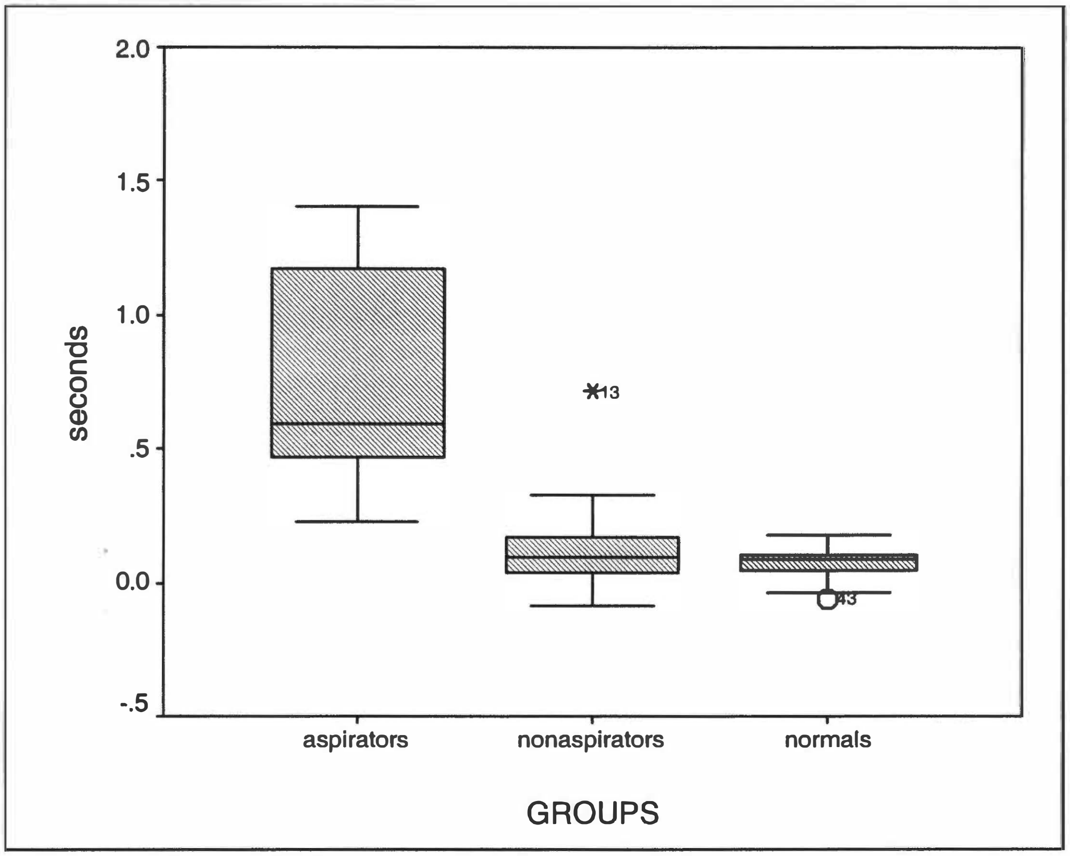

Figure 4-5. Boxplot (in seconds) of the three groups on the DPS

Table 4-8. The test of discrimination functions on the DPS

Test of Function(s)	Wilks' Lambda	df	Sig.
1 through 2	.375	4	.000
2	.977	1	.324

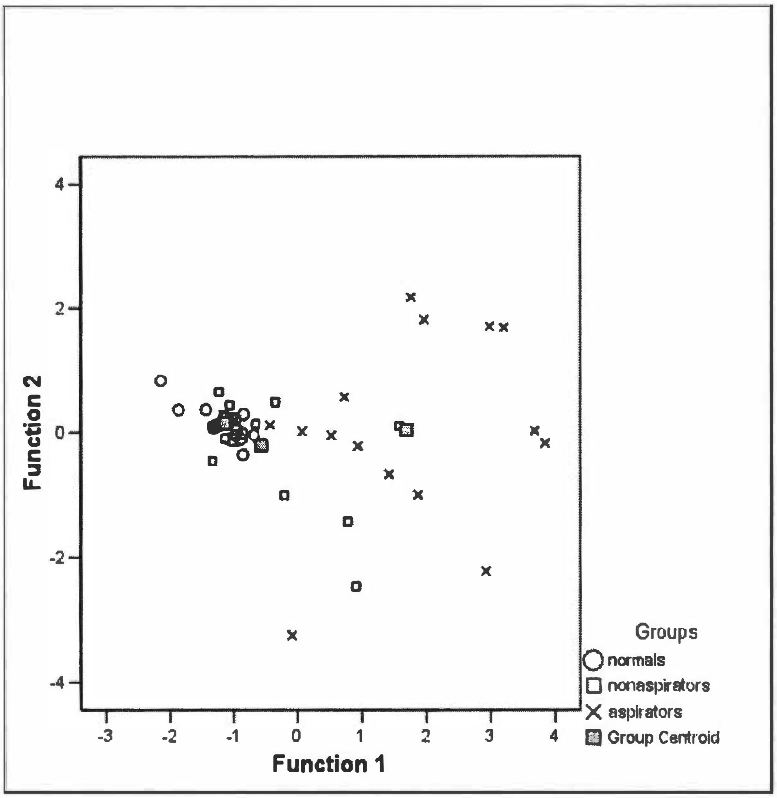

Figure 4-6. The discriminant functions on the DPS

Table 4-9. The classification results on the DPS

Classification Results[a]

		GROUP	Predicted Group Membership: aspirators	nonaspirators	normals	Total
Original	%	aspirators	73.3	26.7	.0	100.0
		nonaspirators	20.0	20.0	60.0	100.0
		normals	.0	20.0	80.0	100.0

a. 57.8% of original grouped cases correctly classified.

For the non-aspirators, only 20% were correctly classified as non-aspirators, whereas 60% were as normal subjects and 20% were as aspirators. For the normal subjects, 80% were correctly classified as normals, whereas 20% were as non-aspirators. Similar to PDT and STD measurements, none of normal subjects was classified as an aspirator. In summary, the normal subjects and the aspirators were classified correctly over 70%, whereas the non-aspirators were only 20% correct. Non-aspirators had the lowest correct classification percentage compared to the aspirators and the normal subjects. Also, 80% of non-aspirators were classified as normal subjects, which suggest that the non-aspirators may belong to the normal group in this measure.

In summary, for all three pharyngeal swallow measures (PDT, STD, DPS), the aspirators were different from both the non-aspirators and the normal subjects.

CHAPTER V

DISCUSSION

1. Comparison among the Three Pharyngeal Swallowing Measurements

In comparison, the Stage Transition Duration (STD) had the highest mean correct classification percentage at 71.1%, whereas Pharyngeal Delay Time (PDT) had 64.4%, and Delayed Pharyngeal Swallow (DPS) had 57.8%. STD had highest mean correct classification percentages across all three groups (see Figure 5-1). These measurements predicted correctly the presence of aspiration for aspirators and the absence of aspiration for the normal subjects over 70% of the time. However, none of the three measurements classified normal subjects as aspirators; but a few normal subjects were classified as non-aspirators. Since both non-aspirators and normal subjects did not have aspirate, this result seems reasonable.

Some aspirators were classified as non-aspirators. Even though the onset of the swallow in relation to bolus flow was similar, factors other than the onset of the swallow could cause the aspiration. Crary and Baldwin (1997) reported that the aspirators had higher and more variable amplitude and shorter duration with poor coordination of swallowing during Surface-Electromyograph (SEMG) traces. Less muscular strength created shorter duration and inefficient use of their existing strength.

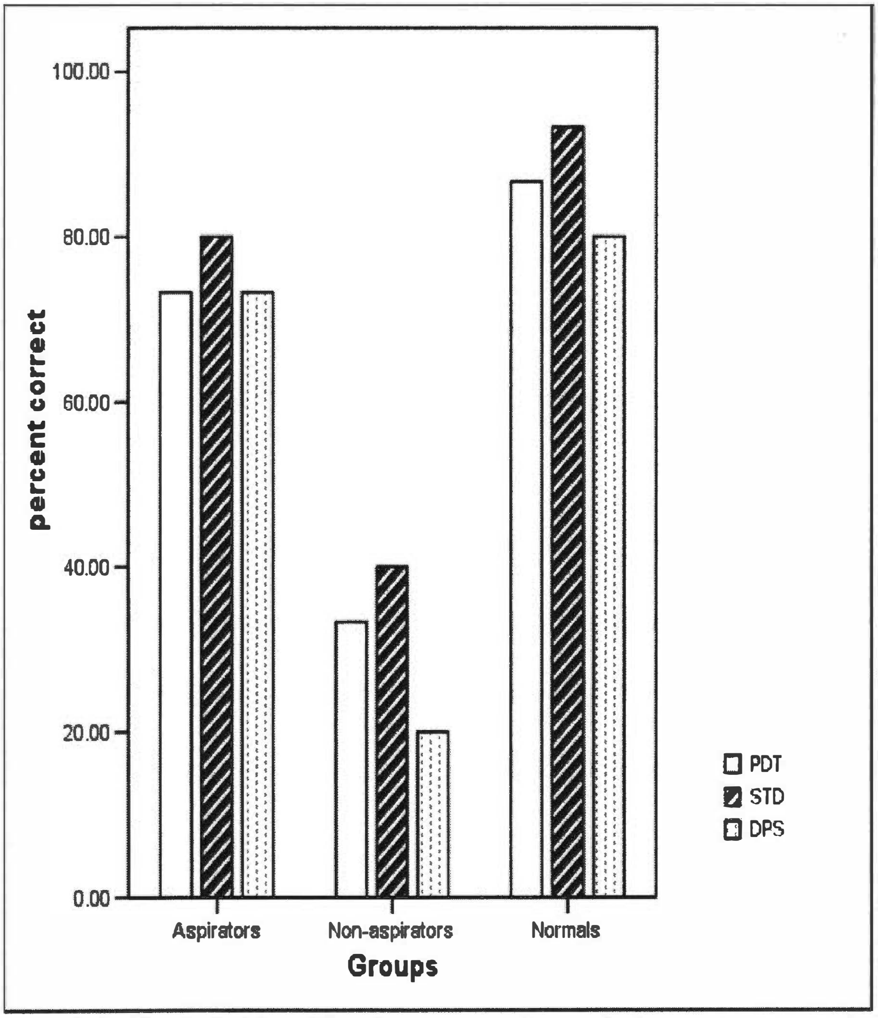

Figure 5-1. Correct classification percentage of three pharyngeal swallowing measurements

In addition, the aspirators who were classified as non-aspirtors may have limited range of movement during hyolaryngeal elevation. Three pharyngeal swallowing measurements of this investigation were designed to use the initiation of hyolaryngeal elevation, but not the range of it. For these aspirators, their initiation of hyolaryngeal elevation was appropriate during the pharyngeal swallowing, but the limited range may reduce their airway protection. Therefore, during a clinical swallowing exam, these aspirators may confuse the clinician's decision for assessment and treatment if the coordination of all muscular activities was not analyzed.

All three pharyngeal measurements had low correct classification percentages for the non-aspirators. Some were classified as the aspirators, but most were classified as normal subjects. This seems reasonable since some stroke patients have not affected swallowing function. Non-aspirators had a slightly slower triggering of pharyngeal swallowing than normal subjects, but this slower triggering was apparently not enough to make them aspirate. These data provide important information on how much delay in a swallowing onset create aspiration.

The only non-aspirator classified as aspirators for all three pharyngeal swallowing measurements was non-aspirator # 13 (see appendix B). He had slow triggering of pharyngeal swallowing similar to the aspirators, but did not have aspiration. Possibly, he had developed a compensatory technique in his oropharyngeal structure, e.g., longer UES opening to avoid aspiration. More research is needed how this can happen.

Overall, the three pharyngeal swallowing measurements showed similar patterns of classification among aspirators, non-aspirators and normal subjects. However, none of the measures showed a significant difference between normal subjects and non-aspirators. This seems reasonable, since both groups did not show an aspiration.

2. Triggering Pharyngeal Swallowing after A Stroke

The data of this investigation supported that the aspirators have a longer duration to trigger their pharyngeal swallowing. The triggering of pharyngeal swallowing for the aspirators occurred over 0.7 sec after the bolus entered their pharynx. The aspirators begin to trigger the pharyngeal swallowing after the bolus is near their vocal folds. This delay might reduce the airway protection, which resulted in aspiration. Other studies support this finding where the aspirators have delayed triggering of pharyngeal swallow and poor laryngeal elevation (Bisch, et al., 1996; Perez, et al., 1998).

In addition to the longer delay, aspirators might have a limited range of movement during the laryngeal elevation and maximum hyoid excursion. This reduced the protection of their airway and the opening of UES. In the normal swallowing, the elevation of hyoid and larynx contributes the airway closure and the anterior movement of hyoid contributes to UES opening (Logemann, 1998). More research is needed on the relationship between range of hyolaryngeal structure and aspiration.

Some aspirators in this study may have had a sensory impairment secondary to their stroke. These may result in an absence of, or a reduction in, sensory feedback. When the liquid entered their airway, the aspirators appear to be unaware or slow to clear the bolus by coughing. In addition, their coughing may not be sufficient to clear all residue. These possible failures and the reductions in sensory feedback might contribute to silent aspiration (Logemann, 1998). Aviv and his colleagues (1996) reported that aspirators had significant sensory deficits in both the pharynx and larynx which result in the aspiration. For example, 40% (2 out of 5) patients with moderate pharynx and larynx sensory impairment and 60% (5 out o f 8) with severe impairment had developed the aspiration (Aviv, et. al, 1996).

In summary, while motor deficits in the larynx and pharynx are thought to be responsible for aspirators, these patients also have sensory deficits, which result in silent aspiration.

3. Clinical Treatment for the Patients with Aspiration

If stroke patients with aspiration have a motor and sensory deficits in pharyngeal swallowing after a stroke, they need specific treatment to improve the triggering of pharyngeal swallowing. These treatment strategies for aspirators are classified as; changes in sensory feedback before swallowing, changes in positioning of head and neck, or movement exercises.

For the change in sensory input for aspirators, Bisch, at al. (1994) and

Lazarus, et al. (1993) reported that increase in viscosity of the bolus decreased the pharyngeal delay time (PDT). This increasing thickness provided the patients with aspiration better awareness of sensory feedback and more time to trigger the pharyngeal swallowing, since the bolus took longer to reach their vocal folds. During the VFSE, clinicians should test these patients with various bolus viscosities and select most effective viscosity for each patient.

Researchers also reported that thermal application reduced pharyngeal delay time (PDT) and stage transition duration (STD) (Lazarrus et al, 1986; Resenbek, et al., 1996). Thermal application was designed to provide an altering sensory stimulus to the brain by rubbing the anterior faucial arch with a cold laryngeal mirror. This facilitates faster pharyngeal swallowing and reduces delay for several swallows after the application. However, the outcomes of thermal application were highly variable both within and across subjects. Clinically, this procedure is not easy for the caregivers or nurses to apply the faucial arch. More research is needed on the effectiveness of this clinical technique.

The Chin-tuck procedure (touching the chin to the neck) helps some patients reduce their aspiration. Chin-tucking pushes the anterior pharyngeal wall posteriorly, narrowing the airway entrance and widening vallecule space (Welch, et al., 1993). The widen space of vallecule and increased epiglottis closure will make the patients to hold the bolus longer until triggering the pharyngeal swallow to facilitate the airway protection. Ertekin, et al. (2001) reported that 55% of patients showed the elimination of aspiration while using the different head and

neck positions like Chin-tuck procedure. Clinically, Chin-tuck procedure is used frequently for the dysphagia patients with delayed triggering of the pharyngeal swallowing. However, the clinicians should be cautious with using this procedure for the patients with pharyngeal muscular deterioration during thick bolus swallowing. This procedure may result in increased retention and aspiration (Bulow, et al., 2002). In addition, Chin-tuck procedure is a compensatory technique, but not the rehabilitative technique. It provides only temporary compensation.

More research is needed on the rehabilitative exercises in pharyngeal swallowing for the stroke patients with aspiration. These exercises attempt to increase the range and precision of laryngeal elevation, vocal fold closure and triggering of pharyngeal swallowing, simultaneously (Crary, 1995). For example, the Mendelsohn maneuver is the voluntary prolongation of laryngeal excursion during swallowing (Kahrilas, et al., 1991). It increases the range and duration of laryngeal elevation, and the opening of UES. (Cook, et al., 1989). It is important for the patients with aspiration to practice these motor skills. Then, the patients may be ready to swallowing (Logemann, 1998). More research is necessary to evaluate the effectiveness of these rehabilitative techniques.

4. Future Study

More research is needed on the relationship between brain lesion and pharyngeal swallowing in patients with a stroke and other neurogenic disorders.

Understanding the effect of different brain lesions may result in an effective strategy for the treatment. There is a variety of oral and hyolaryngeal exercises, compensatory techniques, or changes in bolus consistencies. Even though the patients had similar aspiration during the swallowing, a treatment strategy should be individualized for each patient based on accurate assessment.

During a bedside swallowing exam and a VFSE, some stroke patients demonstrated a voluntary effort for hyoid and laryngeal movements. More research is needed for the patient to maximize their muscular energy effort during swallowing.

CHAPTER VI

CONCLUSION

Based on the results of this study, the following conclusions were formulated:

1. Overall, Stage Transition Duration (STD) had the highest correct classification percent among the three pharyngeal swallowing measurements.
2. All three measures correctly predicted the presence of aspiration for the aspirators and the absence of aspiration for the normal subjects most of the time
3. Non-aspirators were often classified as the normal subjects on all three pharyngeal swallowing measurements.
4. Aspirators showed the longest duration to triggering pharyngeal swallowing. This may be related to their aspiration.
5. Non-aspirators had similar patterns of triggering pharyngeal swallowing as the normal subjects.

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APPENDIX

Appendix A. The Worksheet for Pharyngeal Swallowing Measures

Subject Number/volume		
1. Head of Bolus into the pharynx		
2. Bolus into the pharynx		
3. Begin of Laryngeal Elevation		
4. Begin Max. Elevation of hyoid		
5. Valleculae Entrance of Bolus		

Appendix. B. Raw Data of Three Pharyngeal Swallowing Measurements of Three Subject Groups

Measurements		PDT (5ml)	PDT (10ml)	STD (5ml)	STD (10ml)	DPS (5ml)	DPS (10ml)
Aspira tors	1	.70	.70	.97	.97	.60	.60
	2	.45	.40	.42	.40	.38	.30
	3	.40	.33	.50	.40	.25	.23
	4	1.97	1.50	1.60	1.60	1.36	1.44
	5	1.14	1.43	1.17	1.46	1.00	1.30
	6	1.44	1.17	1.44	1.27	1.37	1.03
	7	1.10	1.73	1.27	2.03	1.03	1.23
	8	1.70	1.17	1.90	1.43	1.40	1.00
	9	.83	.57	1.07	.56	.60	.40
	10	1.40	1.53	1.46	1.60	1.30	1.40
	11	.90	.46	1.13	.66	.70	.36
	12	.27	.23	.27	.45	.45	.26
	13	.87	.42	.93	.47	.80	.35
	14	1.13	.34	1.27	.40	1.00	.19
	15	.60	.47	.77	.60	.50	.37
	N	15	15	15	15	15	15
	Mean	.98	.83	1.08	.95	.84	.69
	SD	.50	.53	.45	.56	.39	.48
	Range	1.84	1.50	1.63	1.63	1.15	1.25
Non-aspira tors	1	.27	.21	.30	.26	.10	.15
	2	.06	.27	.13	.35	-.04	-.13
	3	.60	.10	.64	.21	.47	.00
	4	.30	.26	.35	.30	.19	.19
	5	.14	.10	.12	.10	.04	.02
	6	.06	.10	.13	.15	.00	.03
	7	.30	.07	.37	.14	.23	-.07
	8	.33	.27	.63	.27	.10	.20
	9	.13	.30	.20	.40	.00	.04
	10	.23	.36	.58	.46	.06	.13
	11	.70	.05	.93	.34	.43	-.29
	12	.43	.53	.37	.60	.30	.36
	13	.87	.80	.90	.87	.80	.63
	14	.20	.27	.26	.44	.07	.03
	15	.22	.46	.25	.53	.07	.23
	N	15	15	15	15	15	15
	Mean	.32	.28	.41	.36	.19	.10

	SD	.24	.20	.27	.20	.23	.22
	Range	.81	.75	.81	.77	.84	.92
Normal Subjects	1	.17	.20	.20	.19	.17	.13
	2	.09	.13	.17	.15	-.01	.10
	3	.10	.17	.20	.30	-.17	.10
	4	.17	.18	.20	.19	.04	.08
	5	.14	.19	.22	.26	.11	.15
	6	.24	.20	.26	.38	.11	.07
	7	.16	.17	.12	.18	.10	.10
	8	.15	.16	.19	.20	.12	.10
	9	.20	.23	.27	.34	.07	.13
	10	.15	.23	.15	.26	.09	.07
	11	.15	.19	.08	.14	.08	.12
	12	.18	.23	.23	.17	.15	.20
	13	.28	.07	.33	.19	-.13	.01
	14	.16	.20	.16	.30	.10	.00
	15	.15	.23	.07	.23	.02	.06
	N	15	15	15	15	15	15
	Mean	.17	.19	.19	.23	.06	.09
	SD	.048	.04	.07	.07	.09	.05
	Range	.19	.16	.26	.24	.34	.20

VITA

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