

## Dysphagia in stroke: Development of a standard method to examine swallowing recovery

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**Abstract**—This study began development of a standard method that uses the videofluoroscopic swallow study for evaluation of swallowing recovery after stroke based on a definition of dysphagia derived from three domains: bolus timing, bolus direction, and bolus clearance. Two experiments were conducted: one that defined normal versus disordered swallowing based on the range of scores in a sample of healthy adults ( $n = 13$ ), and one that applied these thresholds to nine stroke patients to identify the presence of dysphagia. Results indicate that acute and protracted dysphagia may be more accurately detected by identifying abnormalities on multiple objective measures of swallowing rather than on laryngeal penetration or aspiration alone. Results indicate that our selected measures and use of healthy control subjects to establish normal thresholds may eventually contribute to the definition and differentiation of dysphagic and nondysphagic patients. Further research with a broader sample of healthy controls and stroke patients is mandatory.

**Key words:** aspiration, bolus clearance, bolus timing, deglutition, deglutition disorder, dysphagia, normal swallowing, Penetration-Aspiration Scale, rehabilitation, stroke, videofluoroscopic swallow study.

### INTRODUCTION

Dysphagia, a disorder of swallowing, has been associated with increased morbidity and mortality following

stroke [1–2]. To date, most studies have focused on the clinical and radiographic presentation of dysphagia in the acute (1–5 days) [3–5] or subacute (21–28 days) [6–7] poststroke phases. Only a few studies have examined swallowing recovery longitudinally following stroke [8–11]. Of these studies, most have used the presence or absence of aspiration to determine swallowing recovery [8–10]. Aspiration was determined as present or absent based on the results of the videofluoroscopic swallow study (VSS) [10] or based on clinical response (cough or choke) to food and liquid presentations [8–9]. The presence or absence of aspiration is an important consideration when examining swallowing recovery in stroke; however, this binary forced-choice method may not be sufficient to accurately

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**Abbreviations:** MRI = magnetic resonance imaging, OTT = oral transit time, P-A = Penetration-Aspiration, PTT = pharyngeal transit time, SD = standard deviation, STD = stage transition duration, UES = upper esophageal sphincter, VAMC = Department of Veterans Affairs medical center, VSS = videofluoroscopic swallow study.

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DOI: 10.1682/JRRD.2005.01.0024

reflect the variability in airway invasion. The Penetration-Aspiration (P-A) Scale is an ordinal scale that evaluates depth, response, and clearance of airway invasion to determine severity (**Table 1**) [12]. Only one study used P-A Scale scores to evaluate airway invasion in a group of stroke patients compared with a group of healthy controls [13]. Results revealed that stroke patients had significantly higher P-A Scale scores than healthy controls. Most control subjects demonstrated no airway invasion (P-A Scale score = 1), and only one healthy elderly adult aspirated (P-A Scale score = 6), whereas five stroke patients aspirated and laryngeal penetration was frequently observed. However, the stroke group was heterogeneous and subjects were examined from 4 to 728 days poststroke. To our knowledge, no study has used this scale in acute and subacute stroke patients to longitudinally examine swallowing recovery.

While airway invasion is important in evaluating swallowing and recovery of function, dysphagia may exist without airway invasion. Other components such as duration of bolus movement through the oropharynx may be impaired and may represent significant dysphagia. As such, bolus timing can be measured with oral transit time (OTT), pharyngeal transit time (PTT), and stage transition duration (STD). OTT is the duration measure of bolus movement through the oral cavity. PTT is the duration measure of bolus movement through the pharynx. STD is the duration between the completion of OTT and the onset of PTT—the point when the pharyngeal swallow is “triggered.” Reduced movement of the oral, pharyngeal, and laryngeal structures may result in bolus retention in the valleculae and/or pyriform sinuses. The valleculae are the pharyngeal recesses bounded by the base of the tongue and the pharyngeal surface of the epiglottis. The pyriform sinuses are the pharyngeal recesses on either side of the larynx. Reduced bolus clearance may produce significant

dysphagia and yield postdeglutitive aspiration. The risk of aspiration increases as the amount of pharyngeal residual increases [14]; therefore, reduced bolus clearance may be another important measure of dysphagia. Bolus clearance is usually not included as an independent measure in the study of dysphagia and has not been examined in the recovery of swallowing function.

Only one study has examined multiple features of swallowing to evaluate the incidence of dysphagia acutely and monitor recovery in stroke patients. Mann et al. used clinical and VSS assessments to evaluate consecutively admitted stroke patients (0–47 days postsymptom onset) [11]. Patients were reevaluated at 6 months; only those initially identified with dysphagia underwent a follow-up VSS. Patients were classified as dysphagic based on airway invasion, duration (delay), and bolus residual. Laryngeal penetration, delayed oral transit, age greater than 70 years, and male sex were identified as independent predictors at baseline of dysphagia, aspiration, or chest infection at 6 months poststroke. Delayed oral transit was the best predictor of failure to achieve prestroke diet. Clinically proven specific and objective measures, however, were not used in the interpretation of the VSS. Aspiration was defined as present or absent, and the amount of aspiration was quantified. However, the amount of aspiration can only be objectively determined with scintigraphy [15] not VSS. Moreover, Mann et al. used subjective measures to define delayed transit times and neither provided a reference point against which they measured the delay (i.e., healthy controls) nor operationally defined abnormal bolus retention.

The current exploratory study (1) begins development of a standard method of using VSS to define dysphagia based on a group of healthy control subjects and (2) applies this method to the examination of swallowing

**Table 1.**  
Penetration-Aspiration Scale.

Aspiration Risk	Score	Classification	Description
No Risk	1	Normal	No airway invasion.
	2	Mild	Bolus enters into airway with clearing.
Risk of Aspiration	3	Moderate	Bolus enters into airway without clearing.
	4	Moderate	Bolus contacts vocal cords with airway clearing.
	5	Moderate	Bolus contacts vocal cords without airway clearing.
Positive Aspiration	6	Severe	Bolus enters trachea and is cleared into larynx or out of airway.
	7	Severe	Bolus enters trachea and is not cleared despite attempts.
	8	Severe	Bolus enters trachea and no attempt is made to clear.

recovery in stroke patients. We conducted two experiments to accomplish this aim. We designed Experiment 1 to develop thresholds for normal versus disordered swallowing based on the range of scores in a sample of healthy adults. We designed Experiment 2 to apply these established thresholds to identify the presence of dysphagia in stroke patients initially and at 1 month poststroke. To determine dysphagia, we used three broad swallowing domains comprising six measures: (1) bolus timing, measured with OTT, PTT, and STD; (2) bolus direction, measured with the P-A Scale; and (3) bolus clearance, measured with vallecular and pyriform sinus residues. We believe that these domains and measures are potentially the most clinically useful in determining dysphagia.

## METHODS

### Experiment 1: Healthy Control Subjects

#### *Subjects*

Control subjects were 13 medically healthy males (mean age  $\pm$  standard deviation [SD] = 62  $\pm$  9 years, range = 50–78 years). Subjects had no history of neurological disease, chronic obstructive pulmonary disease, head and neck cancer, or dysphagia. The study was approved by the Institutional Review Board at Tulane University Health Sciences Center and by the New Orleans Department of Veterans Affairs Medical Center (VAMC), and all control and stroke subjects provided written consent.

#### *Videofluoroscopic Swallow Study*

A VSS was completed on all subjects. VSS samples were recorded with a Super VHS videocassette recorder coupled to a counter timer that encoded digital time in hundredths of a second on each video frame. Lateral images from the oral cavity through the upper esophageal sphincter (UES) were obtained as subjects swallowed 5 mL of liquid barium in two trials. Subjects were instructed to hold the bolus until given the command to swallow. Swallowing domains assessed were bolus timing (OTT, PTT, STD), bolus direction (P-A Scale score), and bolus clearance (vallecular residue score, pyriform sinus residue score). Durations and scores were determined for each swallow across the two trials by slow motion and frame-by-frame analysis of the video recordings and were averaged across the two trials for each subject. The mean and

SD for the control group were determined for each measure in each of the three swallowing domains.

Operational definitions for the bolus timing measures were influenced by previous research [16–18]. OTT was measured from the first video frame in which onset of bolus movement following the command was identified to the first video frame in which the leading edge of the bolus reached the posterior aspect of the ramus of the mandible. Because we wanted to capture the duration of activity in the oral cavity, we measured the first anterior or posterior movement initiated at the bolus head or tail following the command to determine the onset of OTT. PTT was measured from the first video frame in which the leading edge of the bolus reached the posterior aspect of the ramus of the mandible to the first video frame in which the bolus tail passed through the UES. STD was measured from the first video frame in which the leading edge of the bolus reached the posterior aspect of the ramus of the mandible to the first video frame in which onset of maximum superior movement of the hyoid was identified.

We used the P-A Scale to define bolus direction [12]. Scores on this scale range from 1 to 8. A score of 1 indicates no airway invasion, scores 2 to 5 indicate laryngeal penetration, and scores 6 to 8 indicate aspiration (**Table 1**).

Bolus clearance was rated on an ordinal scale from 1 to 3 for both the valleculae and pyriform sinus residue [17]. A score of 1 indicated no residual to mild bolus retention. A score of 2 represented moderate residual with up to half the recess filled with material postswallow. A score of 3 represented severe residual with more than half the recess filled with material postswallow.

We determined a priori that we would identify values greater than 2 SD above the control group mean as the threshold of disordered swallowing on any of the six measures in any of the three swallowing domains. That is, dysphagia would be identified if a stroke subject's score was greater than 2 SD above the control group mean on any bolus timing measure (OTT, PTT, STD), the bolus direction measure (P-A Scale), or any bolus clearance measure (vallecular residue, pyriform sinus residue). Because it was unclear whether abnormality on a single measure or a variety of measures was a more stable measure of dysphagia, we also examined the number of measures and domains that were above the normal threshold in the stroke subjects.

## Experiment 2: Stroke Subjects

### Subjects

Stroke subjects were selected from among acute stroke patients ( $n = 37$ ) enrolled in a prospective study of dysphagia at the New Orleans VAMC. Stroke subjects for this case control series consisted of nine males (mean age  $\pm$  SD =  $64 \pm 9$  years, range = 54–76 years) consecutively admitted for unilateral nonhemorrhagic stroke. Stroke was confirmed by documentation of an acute single lesion on the diffusion weighted imaging sequence of the magnetic resonance imaging (MRI) scan. Subjects were admitted, on average, within 24 hours of symptom onset (range = 0–2 days), and MRI scans were completed, on average, within 2 days of admission (range = 0–4 days). Five subjects presented with unilateral right-hemispheric damage, and four with unilateral left-hemispheric damage. The stroke subjects had no prior history of neurological disease, including previous stroke, dysphagia, or head and neck cancer.

### Videofluoroscopic Swallow Study

The method for conducting the VSS was identical to that for the control subjects. All stroke subjects were examined at Time 1 (average 2 days from admission, range 1–3 days) and Time 2 (average 33 days poststroke, range 26–48 days). Stroke subjects were classified as dysphagic if they had transit times or scores greater than 2 SD above the control group mean on any of the three bolus timing measures (OTT, PTT, STD), the P-A Scale, or the two bolus clearance measures (vallecular residue, pyriform sinus residue). In addition, the number of measures and swallowing domains that were abnormal as compared with the control group was identified for each stroke subject.

### Reliability

Inter- and intrarater reliabilities of bolus-timing duration measures (OTT, PTT, STD), P-A Scale score, and bolus clearance measures (valleculae, pyriform sinus) were completed with the intraclass correlation coefficient (ICC). We assessed reliability in 10 randomly selected subjects (6 stroke, 4 controls) after averaging measures across the two 5 mL trials. ICC revealed inter- and intrarater reliabilities of ICC  $>0.90$  for all measures except the intrarater P-A Scale score, ICC = 0.889. Because reliability was examined in more than 40 percent of our subjects (which is more than that typically measured in

studies) and our reliability was high, reliability was not repeated with the whole sample.

## RESULTS

### Experiment 1: Healthy Control Subjects

Mean and SD for individual subjects are summarized in **Table 2** and the **Figure**. Group analyses for each measure are summarized below.

#### Bolus Timing

The OTT average was 0.46s (SD = 0.32, range = 0.13–1.15). The PTT average was 0.84s (SD = 0.15, range = 0.55–1.12). The STD average was  $-0.12$ s (SD = 0.19, range =  $-0.33$ –0.37). Based on a definition of abnormal as  $>2$  SD above the mean for the control group, subjects with OTT scores  $>1.10$ s, PTT scores  $>1.14$ s, and STD scores  $>0.26$ s were considered dysphagic. When applying this metric to identify the threshold between normal and disordered swallowing, we identified two healthy control subjects with a single bolus-timing measure above the threshold for normal. A 57-year-old subject (C12) demonstrated an average OTT of 1.15 s. He held the bolus at the front of the oral cavity in preparation for the command. A 67-year-old subject (C9) displayed an average STD of 0.37s with pharyngeal pooling identified.

#### Bolus Direction

The average P-A Scale score for the control group was 1.12 (SD = 0.42, range = 1–2.5). We identified an average P-A Scale score of  $>2$  as dysphagic using  $>2$  SD above the mean for controls. Except for one subject, all controls demonstrated no airway invasion (P-A Scale score 1) on both 5 mL trials. Control subject C11 had a P-A Scale score of 4 on the first swallow and 1 on the second swallow. His average P-A Scale score was 2.5, which was above the threshold for normal.

#### Bolus Clearance

The average valleculae and pyriform sinus residue scores were both 1 (SD = 0), which indicates that the control subjects demonstrated mild to no pharyngeal residue. Based on findings from the control subjects, subjects with pharyngeal residue scores of  $>1$  for either the valleculae or pyriform sinuses were considered dysphagic.

## Experiment 2: Stroke Subjects

Durations and scores for all swallowing measures obtained acutely poststroke (Time 1) and at 1 month (Time 2) are shown in **Table 3** and the **Figure**.

### Time 1

We classified subjects with dysphagia based on our a priori definition of 2 SD above the control group's means on any of the six measures in the three swallowing

domains of bolus timing (OTT, PTT, STD), bolus direction (P-A Scale score), and bolus clearance (vallecular residue score, pyriform sinus residue score). These specific dysphagia scores, as defined by our control cohort, were OTT: >1.10s, PTT: >1.14s, STD: >0.26s; P-A Scale: score >2; residue scale: score >1. Using these criteria and abnormality on only a single measure to determine dysphagia, we classified six (67%) of nine stroke

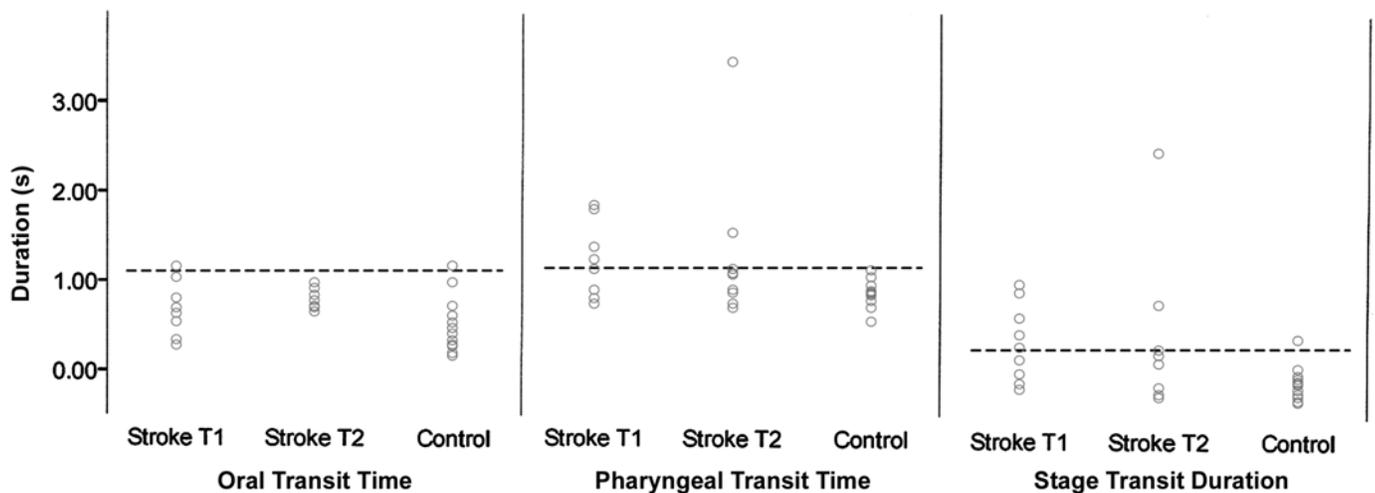
**Table 2.**

Scores for individual control subjects on bolus timing, direction, and clearance swallowing measures.

Control Subject	Age	Bolus Timing (s)			Bolus Direction P-A Scale	Bolus Clearance	
		OTT	PTT	STD		Valleculae	PS
C1	61	0.51	0.79	-0.27	1	1	1
C2	59	0.15	0.96	-0.13	1	1	1
C3	50	0.25	0.55	-0.04	1	1	1
C4	53	0.13	0.71	-0.10	1	1	1
C5	59	0.31	0.87	-0.32	1	1	1
C6	72	0.27	0.84	-0.33	1	1	1
C7	71	0.71	0.90	-0.19	1	1	1
C8	68	0.97	0.89	-0.11	1	1	1
C9	67	0.17	1.12	0.37*	1	1	1
C10	55	0.60	0.78	0.05	1	1	1
C11	54	0.45	1.04	-0.06	2.5*	1	1
C12	57	1.15*	0.70	-0.24	1	1	1
C13	78	0.39	0.85	-0.27	1	1	1
Mean ± SD	—	0.46 ± 0.32	0.84 ± 0.15	-0.12 ± 0.19	1.12 ± 0.42	1 ± 0	1 ± 0

\*Indicates >2 SD above control group mean.

OTT = oral transit time, P-A = Penetration-Aspiration, PS = pyriform sinus, PTT = pharyngeal transit time, SD = standard deviation, STD = stage transit duration.



**Figure.**

Mean duration (s) for control group and stroke group acutely at Time 1 (T1) and at 1 month poststroke, Time 2 (T2). Hatched lines indicate two standard deviations above control subjects' mean scores.

**Table 3.**

Scores for stroke subjects on acute and subacute (1 month) swallowing measures.

Stroke Subject	Age	Lesion Site	Acute						Subacute					
			Timing			Direction	Clearance		Timing			Direction	Clearance	
			OTT	PTT	STD	P-A Scale	Valleculae	PS	OTT	PTT	STD	P-A Scale	Valleculae	PS
S1	76	R	0.62	1.86*	0.90*	8*	1	2*	—	1.09	0.20	3*	1	1
S2	54	R	0.80	1.39*	0.63*	1.5	1	1	0.77	1.15*	0.10	2	1	1
S3	74	R	0.26	1.81*	1.00*	8*	1	1	0.69	3.47*	2.47*	1	1	1
S4	56	R	0.33	0.74	-0.18	1	1	1	0.83	0.70	-0.27	1	1	1
S5	56	R	0.68	0.81	0	1.5	1	1	0.90	0.74	-0.16	1	1	1
S6	63	L	0.27	0.75	-0.12	1.5	1	1	0.70	0.90	0.20	1	1	1
S7	73	L	1.03	1.24*	0.44*	1	1	1	0.63	1.54*	0.77*	1	1	1
S8	56	L	0.54	0.90	0.16	2.5*	1	1	0.63	0.87	-0.23	1	1	1
S9	67	L	1.16*	1.15*	0.30*	1	1	1	0.97	1.07	0.27*	1	1	1

\*Durations &gt;1.10 s for OTT, 1.14 s for PTT, and &gt;0.26 s for STD, P-A Scale &gt;2, and residual scores &gt;1 classified as dysphagia.

L = left hemisphere, OTT = oral transit time, P-A = Penetration-Aspiration, PS = pyriform sinus, PTT = pharyngeal transit time, R = right hemisphere, STD = stage transit duration.

subjects as dysphagic. One (11%) of the 9 subjects demonstrated dysphagia on a single measure, whereas the remaining five stroke subjects with dysphagia (56%) demonstrated dysfunction on multiple measures. Four of the six dysphagic subjects demonstrated abnormalities in only one domain (bolus timing or bolus clearance), whereas the remaining two dysphagic subjects demonstrated abnormalities in multiple domains (stroke subject S1: bolus timing, bolus direction, bolus clearance; stroke subject S3: bolus timing, bolus direction).

Analysis of the specific domains revealed that five stroke subjects demonstrated abnormalities in bolus timing, with all these subjects displaying abnormal transit in multiple measures. Specifically, one (11%) of nine subjects demonstrated abnormal OTT, five (56%) demonstrated abnormal PTT, and five (56%) demonstrated abnormal STD. Analysis of bolus direction revealed that three (33%) of the nine stroke subjects' scores were above the threshold for normal in this domain. One stroke subject (S8) had an average P-A Scale score of 2.5, but he did not demonstrate swallowing dysfunction in other domains. Two stroke subjects (S1 and S3) each had an average P-A Scale score of 8, indicating silent aspiration. They also demonstrated dysphagia in other swallowing domains. Only one (11%) of nine stroke subjects demonstrated a bolus clearance average score >1. This stroke subject (S1) had an average score of 2 for pyriform sinus residue and also demonstrated abnormalities in bolus direction and multiple measures of bolus timing.

### Time 2

At 1 month poststroke, only one stroke subject demonstrated resolution of dysphagia. This subject (S8) demonstrated dysphagia only on a single measure (P-A Scale score of 2.5) at Time 1, whereas his P-A Scale score was 1 at Time 2. Four of the five remaining subjects who were initially classified with dysphagia on multiple measures at Time 1 showed some recovery of function on at least one swallowing measure at Time 2, yet none improved to normal thresholds, as determined by the control subjects, on every swallowing measure. Only one stroke subject (S7) demonstrated no improvement in any swallowing measure; in fact, he demonstrated slight worsening in the two bolus timing measures that were initially disordered at Time 1. The three subjects without dysphagia at Time 1 continued to demonstrate intact swallowing on the VSS at Time 2.

Five stroke subjects presented with dysphagia in multiple measures at Time 1. At Time 2, three of these stroke subjects demonstrated abnormalities in only a single measure. Two of these subjects demonstrated abnormalities on a single bolus-timing measure (S2 and S9). These two subjects had a transit time that was only 0.01 s above the threshold for normal in either PTT or STD. One stroke subject (S1) demonstrated abnormality only in bolus direction. This subject presented with an average P-A Scale score of 8 at Time 1 but of 3 at Time 2. Two stroke subjects (S3 and S7) presented with continued abnormalities in two measures of bolus duration. At Time 2, no subject presented with abnormalities in more than two measures and none demonstrated abnormalities across domains.

Specific analysis of bolus timing revealed that no subject demonstrated abnormal OTT at Time 2. Four stroke subjects (44%) continued to display increased PTT or STD as compared with five subjects (56%) at Time 1. However, two of these four subjects demonstrated reductions in their duration time. The remaining two subjects with continued increased timing demonstrated longer PTT and STD at Time 2 as compared with Time 1. All three stroke subjects (S1, S3, and S8) who had abnormal bolus direction at Time 1 demonstrated improvements at Time 2. Subject S1 had an average P-A Scale score of 8 at Time 1, but of 3 at Time 2, which indicated laryngeal penetration with residual. The remaining subjects, including S3 and S8, demonstrated no airway invasion on either trial at Time 2. All subjects demonstrated a bolus clearance score of 1 for the valleculae and the pyriform sinuses.

## DISCUSSION AND CONCLUSIONS

This exploratory study aimed to (1) develop a standard method of using VSS for defining dysphagia based on a group of healthy control subjects and (2) apply this method for examining swallowing recovery in stroke patients. We used six measures of swallowing performance in three broad domains to objectively define dysphagia: bolus timing (OTT, PTT, STD), bolus direction (P-A Scale), and bolus clearance (vallecular residue, pyriform sinus residue). While many measures can be used for evaluation of swallowing, we selected these specific measures order to reflect all the multiple dimensions for oropharyngeal swallowing, which might, in turn, constitute a clinically useful measure of dysphagia. Dysphagia was identified if stroke subjects scored greater than 2 SD above the control group mean on any of these six swallowing measures. We identified abnormality on all the different measures and across the three domains because it was unclear whether dysfunction on a single measure represented a more stable determinant of dysphagia than dysfunction on a variety of measures. Because this was the first step in our development of a standard measure of dysphagia, we evaluated stroke subjects as individuals and therefore needed group descriptive data for the control group to compare with individual stroke subjects. Results suggest that the most robust definition of dysphagia should be based on abnormality on at least two swallowing measures. This is the first study to use objectively defined measures based on healthy control

subjects to longitudinally examine swallowing recovery in a group of stroke patients upon hospital admission and at 1 month poststroke.

In this exploratory study, we initially used a cohort of 13 healthy control subjects to determine a range of “normal” or nondysphagic bolus transit times, P-A Scale scores, and amount of pharyngeal residue. While we established a threshold for normal for each swallowing measure, three control subjects surpassed this threshold on a single measure. Two control subjects had a single duration measure that was above the cutoff for the control group, and one demonstrated a P-A Scale score above threshold. These three control subjects did not have medical diagnoses that might have contributed to abnormal swallowing and did not report any dysphagia, thus they cannot be considered dysphagic but instead may represent the outer limits of normal. Factors concerning our sample may have contributed to the above-threshold findings in these three control subjects. Based on our analysis, a much larger sample of controls is clearly necessary. For a standard measure to be clinically useful, it must be determined with a large sample. Results must be reviewed as preliminary until this measure can be used with a larger number of subjects. In addition, because our healthy control subjects were matched for age with our stroke group, the age range for our control group was fairly restricted (mean = 62 years, 62% were younger than age 65). Previous research has found that longer transit times and increased age are associated [19–20], and that in older populations, the point at which swallowing may differ notably from younger subjects is between the ages of 65 and 70 [21–22]. As such, a larger sample size that incorporates a greater number of healthy adults over the age of 65 may provide a more accurate range of normal transit times and better delineate dysphagia from normal variances in swallowing.

Sixty-seven percent of the unilateral stroke subjects demonstrated dysphagia on at least one swallowing measure when they were evaluated initially following stroke. At 1 month, we identified improvement on a least one swallowing measure in five of the six subjects initially classified with dysphagia, which supports previous research suggesting improvement in swallowing function at 3 to 4 weeks poststroke [23].

These results indicate that our selected measures and use of healthy control subjects to establish thresholds for normal may eventually contribute to the definition and differentiation of dysphagic and nondysphagic patients. However, creating a completely satisfactory definition

for dysphagia is extremely complex and may well require additional measures and more complex scoring systems for the most accurate identification of dysphagia and recovery in stroke patients. Functional recovery may be equally important as physiologic recovery in measuring acute and protracted dysphagia. In future research, we plan to incorporate the "SWAL-QOL" [24], a psychometrically sound measure of swallowing quality of life, in the measurement of dysphagia and recovery.

At Time 1, all but one of the six stroke subjects with dysphagia demonstrated dysfunction on multiple measures. These five subjects showed abnormalities in multiple timing measures, whereas two also demonstrated dysfunction across domains. The single subject who demonstrated only one abnormal measure at Time 1 had a P-A Scale score of 2.5; the threshold was 2. At Time 2, only two subjects continued to demonstrate dysfunction on multiple measures; in fact, both demonstrated worse transit times at 1 month. The remaining three subjects demonstrated dysfunction on only a single measure: two subjects displayed abnormal durations on only a single timing measure, with the deviant transit times only 0.01 s above the cutoff for normal duration; and one had a P-A Scale score of 3. These results, three control subjects demonstrating scores above threshold for a single measure, suggest that combined measures versus a single measure may differentiate the patients with dysphagia, at least in this sample.

All three swallowing domains appear to be important in identifying dysphagia and recovery. We selected three measures to assess bolus timing: OTT, PTT, and STD. At Time 1, the five stroke subjects who displayed dysfunction in this domain demonstrated abnormalities on multiple measures. At Time 2, the two subjects who demonstrated abnormalities on multiple measures of bolus timing demonstrated even longer transit times than at Time 1. Of the remaining three subjects, two demonstrated dysfunction on only a single timing measure and one demonstrated transit times within the normal range. Bolus timing appears to objectively measure swallowing function, particularly when at least two measures in this domain are disordered. Notably, however, we used command swallows to measure bolus timing. We acknowledge that swallowing to command may influence transit times; however, at the time that we conducted the study, this was the standard for assessing timing. Future research should evaluate measures to command and undirected measures to evaluate influences on bolus timing.

P-A Scale scores demonstrated the greatest magnitude of change in stroke subjects from the initial to follow-up evaluation. The two subjects who presented with silent aspiration (P-A Scale score 8) initially post-stroke demonstrated either no airway invasion (P-A Scale score 1) or laryngeal penetration with stasis (P-A Scale score 3) at 1 month poststroke. The one stroke subject who had an average P-A Scale score of 2.5 at Time 1 presented with no airway invasion at Time 2. Our cases, however, reflect the importance of determining acute and protracted dysphagia with multiple measures of swallowing, not just airway invasion. If airway invasion had been the only parameter, as in previous studies [8–10], only three of our subjects would appear to have dysphagia in the acute phase of stroke and only one subject would appear to have persistent dysphagia at 1 month. However, our bolus-timing and bolus-clearance measures indicate otherwise, particularly when one examines the results of the one subject who demonstrated silent aspiration acutely following the stroke but no airway invasion at 1 month yet continued to present with disordered bolus timing.

In our group of stroke subjects, pharyngeal residue was normal to mild in all but one subject. This may reflect the volume and viscosity of the bolus that was measured. Our findings were based on the swallowing of 5 mL of liquid barium, which may yield residue in only the most severe cases. Future studies evaluating larger volumes and viscosities of barium may indicate that pharyngeal residue has a greater role in the identification of dysphagia and recovery of swallowing.

## ACKNOWLEDGMENTS

This material was based on work supported by the Department of Veterans Affairs, Rehabilitation Research and Development, through a career development grant to Dr. Daniels, grant B3019V; and by the Tulane-Charity-Louisiana State University General Clinical Research Center, grant M01-RR05096.

The authors have declared that no competing interests exist.

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Submitted for publication January 21, 2005. Accepted in revised form July 8, 2005.