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Pharyngeal Effects of Bolus Volume, Viscosity, and Temperature in Patients With Dysphagia Resulting From Neurologic Impairment and in Normal Subjects

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The oropharyngeal swallow of 10 patients with mild dysphagia at 3 weeks after a cerebrovascular accident (stroke), 10 normal subjects, and 8 neurologically impaired patients with moderate to severe dysphagia was studied videofluorographically to examine the effects of 2 bolus temperatures (room temperature and 33°F), 2 volumes, and 2 viscosities on the durations of pharyngeal stage swallow events and the frequency and nature of oropharyngeal swallowing problems and bolus transit. Normal subjects exhibited significantly longer pharyngeal response times and longer laryngeal elevation only for 1 ml cold liquid. The stroke patients and the 8 significantly dysphagic neurologically impaired patients exhibited very few significant effects of temperature on swallowing disorders or swallow measures. Increases in bolus volume and viscosity decreased pharyngeal delay times in both neurologically impaired patient groups. Stroke patients exhibited significantly longer pharyngeal delay times but shorter pharyngeal response times, laryngeal closure, cricopharyngeal opening, and laryngeal elevation than normal subjects on some bolus volumes and viscosities. Results are discussed in terms of the potentially therapeutic effects of bolus volume and viscosity.

KEY WORDS: swallowing, bolus volume, temperature, videofluoroscopy, pharynx

Bolus volume and viscosity have been found to systematically change some measures of oropharyngeal swallow physiology in normal subjects (Jacob, Kahrilas, Logemann, Shah, & Va, 1989; Kahrilas, Lin, Logemann, Ergun, & Facchini, 1993; Logemann, Kahrilas, Cheng, Pauloski, Gibbons, Rademaker, & Lin, 1992; Dantas, Kern, Massey, Dodds, Kahrilas, Brasseur, Cook, & Lang, 1990). Duration of airway closure and cricopharyngeal opening increase significantly as bolus volume increases, whereas tongue base movement begins significantly later as volume increases (Jacob, Kahrilas, Logemann, Shah, & Va, 1989; Logemann, Kahrilas, Cheng, Pauloski, Gibbons, Rademaker, & Lin, 1992). Longer oral transit times, longer cricopharyngeal opening, and lower oropharyngeal swallow efficiency have been identified in normal subjects and a heterogeneous group of stroke patients as viscosity increases (Lazarus, Logemann, Rademaker, Kahrilas, Pajak, Lazar, & Halper, 1993). In patients with basal ganglion strokes, increased bolus viscosity resulted in longer pharyngeal delay times and longer pharyngeal transit times. Effects of other bolus characteristics, such as bolus temperature, have not been assessed in normal swallowers or dysphagic patients, despite the fact that degree of sensory input has been found to change the threshold and strength of muscular activation for swallowing (Miller, 1986).

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Delayed triggering of the pharyngeal swallow resulting in increased pharyngeal transit time has been found to be a frequently occurring disorder after neurologic damage (i.e., stroke [Veis & Logemann, 1984; Robbins & Levine, 1988] and closed head injury [Lazarus & Logemann, 1987]). In neurologically impaired dysphagic patients with pharyngeal delay, thermal tactile stimulation (i.e., application of cold pressure to the base of the anterior faucial arches to heighten oral sensory input before a swallow attempt) has been shown to improve triggering of the pharyngeal stage of deglutition in the swallow immediately following the stimulation (Lazzara, Lazarus, & Logemann, 1986). We hypothesized on this basis that a cold bolus (33°) might also have facilitatory effects on the oropharyngeal swallow in dysphagic patients. This study examined the effects of three bolus characteristics (temperature, volume, and viscosity) on measures of the pharyngeal swallow in normal subjects and neurologically impaired patients.

Methods

Subjects

Three groups of subjects were studied. Group 1 consisted of 10 patients (5 men and 5 women) who suffered a single small infarct in the cortex, basal ganglia/internal capsule, or brain stem. They ranged in age from 18 to 85 years (mean age = 62 years) and were judged from a bedside swallow assessment to have a mild dysphagia. No subject in Group 1 had a tracheostomy tube, took concomitant medications (neuroleptics, anticonvulsants, antidepressants, benzodiazepines, antispastics, antihistamines), or demonstrated multifocal lesions or prior medical history that would have put them at risk for any preexisting swallowing disorder. Verification of lesion site and size and presence of only a single infarct was verified from CT or MRI scans uniformly completed at 3 weeks post ictus. At the time of their radiographic swallow study, 9 of these subjects were on full oral diets. One patient was fed via a percutaneous endoscopic gastrostomy (PEG) tube and given nothing by mouth. This patient had been fed via PEG since the stroke because the patient's physician felt dysphagia was present. No referral for swallow assessment had been made before the 3-week videofluorographic assessment.

Group 2 consisted of 10 normal subjects (3 men and 7 women) matched in age ±2 years to the stroke subjects in Group 1. Group 2 subjects had no history of a swallowing problem or any diseases, illnesses, medications, or surgeries involving the central nervous system or head and neck region that might affect swallowing. These normal subjects ranged in age from 21 to 86 years, with a mean age of 62 years. All normal subjects were eating a full oral diet.

Group 3 included a group of 8 neurologically impaired patients (4 men and 4 women) who ranged in age from 54 to 86 years (mean age = 69). Seven of the patients had suffered a stroke and one had undergone neurosurgery for a meningioma. All patients in Group 3 exhibited at least one concomitant factor in addition to their most recent neurologic damage that was thought to put them at increased risk for oropharyngeal dysphagia. These concomitants included multiple strokes, diabetes mellitus, or chronic alcohol abuse. The patients were consecutively referred for a videofluorographic (VFG) study of their oropharyngeal swallow on the basis of a suspected pharyngeal swallow delay from a bedside swallowing assessment, as well as other possible pharyngeal swallow abnormalities. No patient had received any prior dysphagia assessment. All patients exhibited significant dysphagia at bedside, defined as dysphagia that appeared to compromise safety and/or efficiency of the swallow. At the time of modified barium swallow, these 8 patients were on the following diets: 2 patients were on a soft/chopped/pureed diet including all liquids; 1 patient was on a general diet with thick liquids only; 2 patients were on a soft/chopped diet with thick liquids only; 1 patient was on a pureed diet with liquids given nonorally (via PEG); and 2 patients took nothing by mouth (1 was fed via PEG and 1, via nasogastric tube). These diets had been established by the patients' physicians before the patients' referral for the bedside and VFG studies. All patients in Groups 1 and 3 were alert and able to follow simple directions.

Patients were classified into groups by their neurologic status, not according to the results of their bedside assessments. Informed consent was obtained from all subjects.

The Videofluorographic Protocol

Videofluorographic evaluation (modified barium swallow) of the oropharyngeal stages of deglutition was completed with each subject seated and viewed in the lateral plane. The fluoroscopic tube focused on the lips anteriorly, the posterior pharyngeal wall posteriorly, the soft palate superiorly, and the seventh cervical vertebra inferiorly. All swallows were recorded on 3/4 inch videotape. A counter-timer encoded numbers onto each field of the videotape to facilitate slow motion and frame-by-frame analysis of each swallow.

Each subject was given the following bolus types, calibrated for temperature, volume, and viscosity: at most, 4 swallows each of 1 and 5 ml room temperature liquid barium and 4 swallows of 1 ml room temperature (68 to 70°F) barium pudding. Thus, a single subject could be given a maximum of 24 boluses. Larger boluses of pudding were not given in order to reduce aspiration risk. The formulas for mixing the liquid and pudding barium were maintained constant for all subjects, as was the temperature of the boluses. Presentation was not randomized. The same number of swallows at each bolus volume and viscosity was repeated with the barium materials chilled to 33°F. If aspiration occurred, the protocol was discontinued and swallow intervention techniques were introduced to eliminate aspiration (Logemann, 1993). Large volumes were not given in order to minimize the risk of aspiration.

Stroke patients in Group 1 were all assessed uniformly at 3 weeks (±2 days) of their infarction. Patients in Group 3 were assessed at a wide range of time points after their neurologic damage (1 to 9 mos), depending upon when they were referred for swallowing assessment.

Data Reduction

Data reduction was completed by two speech-language pathologists experienced in the analysis of radiographic swallow studies. Each videotape was examined at regular speed, slow motion, and frame-by-frame. First, each videotape was reviewed in real time for the presence of clinical swallow abnormalities. These were tabulated by bolus type for all subjects in each of the three groups. The approximate percentage of the bolus swallowed into the esophagus was noted for each swallow. Pharyngeal transit time (PTT) was determined by defining the time elapsed between bolus head reaching the point where the ramus of the mandible crosses the tongue base and the bolus tail passing through the cricopharyngeal region. Pharyngeal swallow efficiency (PSE) was then calculated for each swallow using the formula: percent of the bolus swallowed into the esophagus divided by pharyngeal transit time. Oral and pharyngeal residue and any aspiration were subtracted from the percent bolus swallowed into the esophagus.

Eight temporal measures were defined for each swallow: (1) pharyngeal delay time (PDT), the period from the head of the bolus passing the point where the ramus of the mandible crosses the tongue (end of the oral stage) to the onset of laryngeal elevation (beginning of the pharyngeal stage); (2) pharyngeal response time (PRT), the period from the onset of laryngeal elevation to the time of cricopharyngeal closure following the passage of the bolus; (3) laryngeal elevation (LAE), the period from the onset of the laryngeal elevation to laryngeal return to rest; (4) laryngeal closure (LAC), onset to offset of laryngeal closure at the entrance to the airway between the epiglottic base and arytenoid; (5) cricopharyngeal opening (CPO), onset to offset of cricopharyngeal opening; (6) posterior tongue base movement (TBM), onset of tongue base retraction to first contact of tongue base to the posterior pharyngeal wall; (7) tongue base contact (TBC), onset to offset of contact of tongue base to the posterior pharyngeal wall; and (8) relationship of onset of laryngeal closure to onset of cricopharyngeal opening (LCPO), that is, the time difference (±) between onset of airway closure and onset of cricopharyngeal opening (time 0). Inter- and intraobserver reliability on all observations and measures was at least .85. These swallow measures were selected because they represent critical physiologic events in the swallow, that is, triggering the pharyngeal swallow, airway protection, cricopharyngeal opening, and tongue base movement.

Data Analysis

A 3-way mixed ANOVA was used to analyze each swallow measure from Groups 1 and 2. This analysis first identified significant interactions among groups (mildly dysphagic stroke patients and normal subjects), bolus type (volume and viscosity), and temperature. If higher-order significant interactions were found, then 2-way ANOVAs were done within subgroups of data. Results are presented by data subgroup if interactions were significant, or pooled over data subgroups if interactions were not significant. Data for Group 3 were analyzed independently of that for Groups 1 and 2 with repeated measures analysis of variance. Pairwise comparisons of bolus types were done using pairwise *t*-tests if the main effect for bolus type was significant. Statistical significance was indicated if $p < .05$.

Results

Results for the comparison of Groups 1 and 2 are presented first, followed by the results from Group 3.

Mildly Dysphagic Stroke Patients and Normal Subjects (Groups 1 and 2)

A maximum of 24 swallows were completed per subject during the videofluorographic evaluation.

Clinical swallowing disorders. Two stroke patients exhibited entirely normal swallows. The other 8 stroke patients exhibited functional swallows enabling oral maintenance of nutrition and hydration. Functional swallows are defined as swallows exhibiting mild abnormalities that do not prevent oral nutrition and hydration on all bolus types. Table 1 presents the types of mild abnormalities observed in 8 of the 10 stroke subjects, and their frequency. Bolus temperature did not affect the nature or frequency of swallow disorders. All normal subjects (Group 2) demonstrated entirely normal swallows with no residue in the oral cavity or pharynx after the swallow.

Overview of Statistical Analysis

Table 2 presents mean (± SEM) for all swallow measures for Groups 1 and 2. The Appendix summarizes in diagram format the results of the statistical analysis for each of the 9 swallow measures, indicating whether there were significant interactions for each measure and how these were treated statistically. Hereafter, results are discussed according to the three variables tested: bolus temperature, group (stroke vs. normal), and bolus volume and viscosity, identifying those measures with significant interactions and any pooling that was done.

Temperature effects. Analysis of temperature effects on the swallow measures revealed significant differences with cold on only 3 swallow measures at the 1 ml liquid volume and 1 measure on 1 ml pudding boluses (Table 3). Normal subjects exhibited significantly longer pharyngeal response times (PRT) and longer laryngeal elevation (LAE) on 1 ml cold liquid boluses (*a* on Table 3). For those measures with no significant interactions involving group, so that stroke and normal groups could be pooled (*b* on Table 3), all subjects exhibited significantly earlier airway closure (LCPO) in relation to cricopharyngeal opening on cold 1 ml liquid boluses and shorter duration of laryngeal elevation (LAE) on cold 1 ml pudding boluses.

Group differences—Stroke vs. normal. Table 4 presents those swallow measures that differed significantly between stroke and normal subjects. On measures that could not be pooled (*a* on Table 4), stroke subjects exhibited significantly shorter pharyngeal response time and shorter laryngeal

TABLE 1. Frequency of swallow disorders (symptoms) observed in the 10 stroke patients in Group 1 during swallows of room temperature and cold boluses of 1 and 5 ml liquid and 1 ml pudding.

Swallow disorder	1 ml Liquid		5 ml Liquid		1 ml pudding	
	Room temp.	33°	Room temp.	33°	Room temp.	33°
Delayed oral initiation	1	1	2	2	1	1
Decreased Tongue Strength:						
Palatal Residue	0	0	1	0	0	0
Tongue Residue	0	0	1	1	0	0
Pharyngeal Delay (between 1 & 2 sec)	4	5	1	0	3	4
Reduced Tongue Base Retraction:						
Tongue Base Residue	0	0	0	0	2	2
Valleculae Residue	2	1	3	3	3	4
Reduced Closure of Laryngeal Vestibule (penetration into airway entrance)	0	0	0	2	1	0
Reduced Cricopharyngeal Opening (pyriform sinus residue)	0	0	1	2	1	2
Aspiration						
During Swallow (reduced laryngeal closure)	0	0	1	0	0	0
After Swallow (reduced tongue base retraction causing vallecular residue)	0	0	0	0	0	1
Total number of swallows	40	40	40	40	30	30

elevation than normal subjects on 1 ml iced liquid boluses. For those swallow measures on which temperature could be pooled (*b* on Table 4), stroke patients exhibited significantly longer pharyngeal delay times (PDT) and shorter duration of laryngeal closure (LAC) than normal subjects on all three bolus types. Several other components of the pharyngeal swallow were also significantly shorter in the stroke subjects on selected boluses. Table 4 (*c*) also presents one swallow measure, duration of cricopharyngeal opening (CPO), for which no temperature or bolus type interactions were found so that these variables could be pooled to show a significantly shorter duration of cricopharyngeal opening in stroke patients.

Bolus volume and viscosity effects. Significant bolus volume and viscosity effects are presented in Table 5. Data for two swallow measures, pharyngeal response time (PRT) and duration of laryngeal elevation (LAE), could not be pooled across group or temperature (*a* on Table 5). The normal subjects exhibited a significant reduction in pharyngeal response time as bolus volume increased on iced liquids and a significantly reduced pharyngeal response time and duration of laryngeal elevation as viscosity increased on iced 1 ml liquid versus iced 1 ml pudding. No such changes were observed in stroke patients on cold or room temperature boluses or in normal subjects on room temperature boluses.

TABLE 2. Mean (±SEM) durations of pharyngeal swallow events in Group 1 (stroke) and Group 2 (normal) during swallows of 1 and 5 ml liquid barium and 1 ml barium pudding at room temperature and 33°. Statistics are based on 39 or 40 swallows for liquid boluses and 30 swallows for pudding boluses. Standard errors appear in parentheses.

Duration measure	1 ml liquid swallows				5 ml liquid swallows				1 ml pudding swallows			
	Normal subjects		Stroke subjects		Normal subjects		Stroke subjects		Normal subjects		Stroke subjects	
	Cold	Rm temp.	Cold	Rm temp.	Cold	Rm temp.	Cold	Rm temp.	Cold	Rm temp.	Cold	Rm temp.
Pharyngeal Delay Time (PDT)	.22 (.16)	−.01 (0.7)	1.42 (.56)	.80 (.33)	−.04 (.05)	−.06 (.05)	.04 (.05)	.08 (.06)	.05 (.08)	−.03 (.08)	.46 (.18)	.34 (.18)
Pharyn. Response Time (PRT)	1.07 (.09)	.88 (.04)	.85 (.03)	.97 (.10)	.94 (.05)	.95 (.05)	.83 (.02)	.83 (.02)	.88 (.03)	.99 (.07)	.87 (.03)	.85 (.02)
Laryn. Elevation (LAE)	1.50 (.09)	1.31 (.06)	1.19 (.04)	1.34 (.08)	1.41 (.08)	1.41 (.07)	1.24 (.05)	1.22 (.04)	1.15 (.06)	1.36 (.10)	1.22 (.04)	1.26 (.06)
Laryn. Closure (LAC)	.44 (.03)	.42 (.06)	.38 (.02)	.40 (.02)	.63 (.06)	.54 (.04)	.38 (.02)	.40 (.02)	.44 (.02)	.47 (.04)	.39 (.03)	.40 (.03)
Cricopharyngeal Opening (CPO)	.47 (.02)	.45 (.02)	.41 (.01)	.47 (.02)	.54 (.01)	.54 (.02)	.54 (.01)	.54 (.01)	.50 (.02)	.50 (.01)	.47 (.02)	.46 (.02)
Tongue Base Movement (TBM)	.28 (.02)	.27 (.01)	.30 (.02)	.29 (.02)	.24 (.02)	.25 (.02)	.27 (.01)	.27 (.02)	.30 (.03)	.26 (.03)	.27 (0.2)	.25 (.01)
Tongue Base Contact (TBC)	.29 (.02)	.28 (.02)	.28 (.02)	.32 (.03)	.27 (.02)	.25 (.02)	.24 (.01)	.24 (.01)	.26 (.02)	.27 (0.2)	.26 (.02)	.26 (.02)
Pharyn. Swallow Efficiency (PSE)	111 (8)	134 (7)	103 (10)	107 (11)	124 (6)	125 (6)	129 (6)	124 (6)	123 (7)	113 (8)	108 (10)	119 (10)
1st Airway Closure to 1st Cricoph. Opening (LCPO)	−.07 (.02)	−.01 (.01)	−.01 (.02)	.02 (.02)	−.16 (.05)	−.06 (.03)	.07 (.02)	.07 (.02)	−0.4 (.01)	−.03 (.02)	.00 (.02)	−.01 (.02)

TABLE 3. Significant temperature effects (room temperature vs. iced) on those swallowing measures with significant interactions with group and bolus (a), and no group interactions so the stroke patients (Group 1) and normal subjects (Group 2) could be pooled (b). Standard errors appear in parentheses.

	Rm. temp.	Iced	Mean diff.	*p*-Value
a) No Pooling (Group 2: Normal subjects)				
Pharyngeal Response Time (PRT) 1 ml Liquid	.88 (.04) (n = 40)	1.07 (.09) (n = 40)	−1.9	.02
Duration of Laryngeal Elevation (LAE) 1 ml Liquid	1.31 (.06) (n = 40)	1.50 (.09) (n = 40)	−.19	.04
b) Pooled Across Groups				
1st Airway Closure to 1st Cricopharyngeal Opening (LCPO) 1 ml Liquid	.00 (.01) (n = 80)	−.04 (.01) (n = 80)	+.05	.004
Duration of Laryngeal Elevation (LAE) 1 ml Pudding	1.31 (.06) (n = 60)	1.19 (.04) (n = 60)	+.12	.04

For those swallowing measures with no interaction involving temperature (*b* on Table 5), data for cold and room temperature swallows were pooled to examine bolus volume and viscosity effects. With an increase in bolus volume (1 to 5 ml), stroke patients exhibited significantly shorter pharyngeal delay times and later closure of the airway in relation to opening of the cricopharyngeal region. With an increase in bolus volume, normal subjects revealed longer airway clo-

TABLE 4. Significant group effects (stroke vs. normal) on those swallowing measures with significant interactions involving bolus temperature so no pooling was possible (a); no interactions involving temperature so room temperatures and iced could be pooled (b); and no temperature or bolus type interactions so room temperature and iced and bolus type (1 ml and 5 ml liquid and 1 ml pudding) could be pooled (c). Standard errors appear in parentheses.

Swallow measure	Bolus type	Mean (SEM) Stroke	Mean (SEM) Normal	Mean diff.	*p*-Value
a) No Pooling					
Pharyn. Response Time (PRT)	1 ml liq. iced	.85 (.03) (n = 40)	1.07 (.09) (n = 40)	−.22	.01
Duration of Laryn. Elevation (LAE)	1 ml liq. iced	1.19 (.04) (n = 40)	1.50 (.09) (n = 40)	−.31	.0005
b) Pooled Temperature					
Pharyngeal Delay Time (PDT)	1 ml liquid[a]	1.11 (.33) (n = 79)	.10 (.09) (n = 80)	1.01	.002
	5 ml liquid[a]	.06 (.04) (n = 80)	−.05 (.04) (n = 79)	.11	.03
	1 ml pudding[a]	.40 (.13) (n = 60)	.01 (.06) (n = 60)	.39	.005
Duration of Laryn. Closure (LAC)	1 ml liquid[a]	.38 (.01) (n = 80)	.43 (.02) (n = 80)	−.05	.007
	5 ml liquid[b]	.39 (.01) (n = 80)	.58 (.04) (n = 79)	−.19	<.0001
	1 ml pudding[b]	.39 (.02) (n = 60)	.45 (.02) (n = 60)	−.06	.004
Pharyngeal Response Time (PRT)	5 ml liquid	.83 (.02) (n = 80)	.94 (.03) (n = 79)	−.11	.001
	1 ml pudding	.86 (.02) (n = 60)	.93 (.04) (n = 60)	−.07	.03
Duration of Laryn. Elevation (LAE)	5 ml liquid	1.23 (.03) (n = 80)	1.41 (.06) (n = 79)	−.18	.001
1st airway Closure to 1st Cricopharyngeal Opening (LCPO)	1 ml liquid	.01 (.01) (n = 80)	−.04 (.01) (n = 80)	.05	.002
	5 ml liquid	.07 (.01) (n = 80)	−.11 (.03) (n = 79)	.05	<.0001
c) Pooled Temperature and Bolus Duration of Cricopharyngeal Opening (CPO)		.48 (.01) (n = 220)	.50 (.01) (n = 220)	−.02	.03

[a]For PDT, the three differences (1.01, 0.11, and 0.39) are significantly different, $p = .008$.
[b]For LAC, the three differences (−.05, −.19, and −.06) are significantly different, $p < .0001$.

TABLE 5. Significant volume effects (1 ml liquid vs. 5 ml liquid) or viscosity effects (1 ml liquid vs. 1 ml pudding) on those swallowing measures with significant interactions involving group (stroke and normal), temperatures (room temp. and iced), and bolus type (1 ml liquid, 5 ml liquid, and 1 ml pudding) so no pooling was possible (a); no interactions involving temperature so room temperatures and iced could be pooled (b); and no significant interactions so room temperature and iced and stroke (Group 1) and normal (Group 2) subjects could be pooled (c). Standard errors appear in parentheses.

	Mean (SEM)				
	1 ml liq.	5 ml liq.	1 ml pudding	ANOVA *p*	Pair*
a) No Pooling					
Pharyngeal Response Time (PRT) Normal: Iced	1.07 (.09) (n = 40)	.94 (.05) (n = 40)	.88 (.03) (n = 30)	.02	1,2
Duration of Laryn. Elevation (LAE) Normal: Iced	1.50 (.09) (n = 40)	1.41 (.08) (n = 40)	1.15 (.06) (n = 30)	.0006	2
b) Pooled Temperature					
Pharyn. Delay Time (PDT) Stroke	1.11 (.33) (n = 79)	.06 (.04) (n = 80)	.40 (.13) (n = 60)	.0002	1,2
1st airway Closure to 1st Cricopharyn. Opening (LCPO) Stroke	.01 (.01) (n = 80)	.07 (.01) (n = 80)	−.01 (.01) (n = 60)	<.0001	1
Duration of Airway Closure (LAC) Normal	.43 (.02) (n = 80)	.58 (0.4) (n = 79)	.45 (.02) (n = 60)	<.0001	1
1st airway Closure to 1st Cricopharyn. Opening (LCPO) Normal	−.04 (.01) (n = 80)	−.11 (.03) (n = 79)	−.04 (.01) (n = 60)	.01	1
c) Pooled Temp. & Group					
Pharyn. Swallow Efficiency (PSE)	114 (5) (n = 159)	125 (3) (n = 159)	116 (4) (n = 119)	.03	1
Duration of Cricopharyn. Opening (CPO)	.45 (.01) (n = 160)	.54 (.01) (n = 159)	.48 (.01) (n = 120)	<.0001	1,2
Duration of Tongue Base Contact (TBC)	.29 (.01) (n = 160)	.25 (.01) (n = 159)	.26 (.01) (n = 120)	<.0001	1,2

*Pairwise comparisons: 1. $p < .05$ for 1 ml liquid vs. 5 ml liquid. 2, $p < .05$ for 1 ml liquid vs. 1 ml pudding.

sure durations and earlier closure of the airway in relation to cricopharyngeal opening. With an increase in bolus viscosity (1 ml liquid to 1 ml pudding), stroke patients exhibited significantly shorter pharyngeal delay times.

For those measures on which bolus temperature and group could be pooled (*c* on Table 5), results showed increased pharyngeal swallow efficiency, prolonged cricopharyngeal opening, and shorter duration of tongue base contact to the pharyngeal wall as bolus volume increased. The latter two measures changed similarly with increased bolus viscosity.

More Severely Dysphagic Neurologically Impaired Patients (Group 3)

Patients in this group exhibited a wider range of more severe swallowing disorders than the patients in Group 1 (Table 6). No significant change in frequency or nature of swallowing abnormalities was observed during swallows of cold boluses in the more severely dysphagic patients (Table 6).

No significant effects of temperature were seen in Group 3 patients, indicating no significant effects of a cold bolus on any swallow measures in these patients. Therefore, data across bolus temperatures were pooled to examine the effects of bolus volume and viscosity.

Bolus volume effects. Comparison of liquid volumes (1 ml and 5 ml) revealed that (a) pharyngeal delay time (PDT) and pharyngeal transit time (PTT) were significantly shorter on larger (5 ml) bolus volumes; (b) duration of cricopharyngeal opening (CPO) was significantly longer on larger (5 ml) boluses; (c) pharyngeal swallow efficiency (PSE) was significantly greater on 5 ml boluses; and (d) laryngeal closure (LCPO) began significantly earlier on 5 ml boluses (see Table 7).

Bolus viscosity effects. Comparisons of bolus viscosity (Table 7) for 1 ml liquid versus 1 ml pudding boluses revealed (a) significantly longer pharyngeal response times (PRT) on pudding; (b) significantly shorter pharyngeal delay times (PDT) on pudding; (c) significantly shorter pharyngeal transit times (PTT) on pudding; and (d) significantly longer cricopharyngeal opening (CPO) on pudding and earlier airway closure relative to cricopharyngeal opening (LCPO) on pudding boluses.

Discussion

This study examined the effects of bolus temperature (room temperature vs. a cold bolus), bolus volume (1 ml and 5 ml), bolus viscosity (liquid and pudding), and neurologic damage on pharyngeal swallow measures. Subjects in Group 1 (new strokes) were studied at 3 weeks post ictus. Each patient demonstrated a unifocal lesion in the absence of any complicating factors. All of these stroke patients exhibited functional swallowing skills. All were able to maintain oral nutrition and hydration at the time of this assessment, as judged from videofluoroscopy. The functionality of

TABLE 6. Frequency of swallow disorders (symptoms) observed in Group 3 (8 significantly dysphagic neurologically impaired patients) during the swallows of room temperature and cold boluses of 1 and 5 ml liquid and 1 ml pudding. ( ) = aspiration.

Swallow disorder	1 ml liquid		5 ml liquid		1 ml pudding	
	Rm temp.	33°	Rm temp.	33°	Rm temp.	33°
Labial Weakness (loss of bolus from mouth)	4	4	4	3	2	2
No Oral Initiation	1	2	0	0	0	0
Delayed Oral Initiation	4	4	4	4	4	4
Reduced Tongue Control (premature spillage)	4	4	4	4	4	5
Slow tongue movement (slow oral transit)	11	10	10	9	7	7
Decreased Tongue Strength:						
Palatal Residue	0	0	3	2	0	0
Tongue Residue	2	7	9	8	4	4
Pharyngeal Delay (1–55 sec)	15 (1)	12 (1)	14	15	13	12
Reduced Post Tongue Base Motion:						
Tongue Base Residue	0	3	1	2	0	0
Valleculae Residue	2	4	1	3	0	0
Reduced Pharyngeal Contraction (posterior pharyngeal wall residue)	1	0	1	0	0	0
Reduced Closure of Laryngeal Vestibule (penetration into airway entrance)	1	0	2	2	1	1
Reduced Cricopharyngeal Opening (pyriform sinus residue)	2	3	1	2	0	0
Total number of swallows	20	19	20	19	13	12

swallow observed in these subjects may be related at least in part to the lack of other medical factors that may complicate recovery of swallow post stroke or to the small size of their infarcts. The Group 3 patients who exhibited neurologic damage with complicating factors, such as multifocal lesions, diabetes, and/or chronic alcohol abuse, exhibited more severe dysphagia with prolonged transit times and aspiration. Normal subjects did not exhibit any swallowing abnormalities on any boluses presented.

There were very few significant effects of a cold bolus in any of the subject groups. Only the first-time stroke patients (Group 1) exhibited significantly shorter PRT and LAE and earlier LAC on the 1 ml cold boluses. This small volume potentially provides less sensory input as compared to larger volumes of material. It is likely that the cold temperature heightened sensory input for these small liquid boluses and facilitated a faster pharyngeal swallow for this mildly dysphagic group. The 1 ml liquid volume was the most difficult for these stroke patients, judging from the swallow measures. These patients may have some reduced sensory awareness, which increases pharyngeal delay time on small-volume liquid swallows but is not observed on larger volume or increased viscosity boluses because the larger volume or increased viscosity provides increased sensory input. This may explain why some stroke patients have difficulty managing their saliva, as saliva is usually a 1–2 ml volume when swallowed. With reduced sensory awareness, saliva may have to be held in the mouth until it increases to a larger volume before it is recognized and swallowed. This hypothesis is supported by significantly shorter pharyngeal delay times in both neurologic groups (Groups 1 and 3) with boluses of increased volume and viscosity. These changes were not observed in normal subjects (Group 2).

In the normal subjects, 1 ml liquid iced boluses resulted in

TABLE 7. Mean (SEM) pharyngeal measures in Group 3 patients during swallows of 1 ml liquid, 5 ml liquid, and 1 ml pudding. Standard errors appear in parentheses.

	1 ml liq (n = 29–36)	5 ml liq (n = 37–39)	1 ml pudding (n = 24–25)	ANOVA p-value	Pairwise comparisons*
Pharyngeal Delay Time (PDT)	8.24 (1.83)	2.79 (.61)	5.21 (.43)	.0003	1,2
Pharnygeal Response Time (PRT)	0.78 (.02)	0.84 (.02)	0.83 (.02)	.02	2
Pharnygeal Transit Time (PTT)	9.40 (2.00)	3.59 (.65)	6.04 (.44)	.0005	1,2
Duration-Laryngeal Elevation (LAE)	1.21 (.05)	1.29 (.05)	1.23 (.05)	.88	
Duration-Laryngeal Closure (LAC)	0.48 (.04)	0.48 (.03)	0.49 (.05)	.78	
Duration-Cricopharyngeal Opening (CPO)	0.40 (.03)	0.59 (.02)	0.54 (.02)	<.0001	1,2
Duration-Tongue Base Motion (TBM)	0.29 (.02)	0.29 (.02)	0.35 (.02)	.42	
Duration-Tongue Base Contact (TBC)	0.35 (.03)	0.34 (.03)	0.29 (0.3)	.33	
Pharyngeal Swallow Efficiency (PSE)	27 (6)	55 (8)	20 (2)	<.0001	1
Laryngeal Closure to CP Opening (LCPO)	0.05 (.02)	−0.07 (.02)	−0.03 (.02)	<.0001	1,2

*Pairwise comparisons: 1. $p < .05$ 1 ml liquid vs. 5 ml liquid. 2. $p < .05$ 1 ml liquid vs. 1 ml pudding.

longer pharyngeal response times and laryngeal elevation. Cold temperature did not affect any other swallow measures on any volumes or viscosities in the normal subjects. This finding corroborates previous work completed by Knauer, Castell, Dalton, Nowak, and Castell (1990), in which thermal stimulation was found to have no effect on pharyngeal and cricopharyngeal pressure dynamics in normal subjects. It is probable that heightened sensory input does not quicken swallow measures in normal subjects because their sensory input is already optimal, even on a small volume liquid bolus.

Failure of cold to change the swallow in Group 3 (more dysphagic) patients may relate to the extent of their swallow impairment. Their swallow may have been too impaired to be facilitated by the cold bolus, although it was facilitated by increased volume and viscosity. Or, these subjects may have suffered a central sensory deficit that reduced their reception, awareness/recognition, or processing of bolus temperature differences. Despite no significant effect of cold in Group 3 patients, there were individuals who appeared to benefit from the cold bolus, that is, reduced pharyngeal delay times. Thus, despite the generally minimal effects of cold observed in this study, the swallow clinician may find individual dysphagic patients for whom a cold bolus provides therapeutic effects.

Subjects in both stroke groups represented heterogeneous loci of damage in the central nervous system. This may also have accounted for the absence of effects of cold. Additional studies of bolus temperature effects are needed in homogeneous populations of stroke patients.

Despite exhibiting functional swallows, the Group 1 subjects (stroke) were found to differ from normal subjects on a number of pharyngeal swallow parameters, regardless of temperature. Longer PDT for the stroke patients (Group 1) for all bolus volumes and viscosities tested agrees with results from earlier work that has described pharyngeal swallow delay as one of the common problems associated with dysphagia after stroke (Logemann, 1988; Robbins & Levine, 1988; Veis & Logemann, 1984). The delay time was significantly reduced with increased volume and viscosity in both groups of neurologically impaired subjects, emphasizing the possible therapeutic effects of bolus volume and viscosity for some patients and the need to evaluate each patient's reaction to bolus characteristics (volume, viscosity, and temperature) in a systematic way during the radiographic study of oropharyngeal swallow. It is quite likely that the reduction in pharyngeal delay time was greater in Group 3 subjects because their pharyngeal delays were much longer than patients in Group 1 before volume and viscosity changes were introduced.

The stroke patients in Group 1 also exhibited faster pharyngeal response time (PRT) and shorter durations of laryngeal elevation (LAE), laryngeal closure (LAC), and cricopharyngeal opening (CPO) than normal subjects on selected bolus types. These shorter durations may result from a reduced range of laryngeal and pharyngeal movements in the stroke patients. Or, there may be a pharyngeal reflex system that shortens the duration of the neuromuscular events in the pharyngeal stage of swallow if the bolus is located more inferiorly in the pharynx when the pharyngeal swallow triggers, as is seen when there is a pharyngeal swallow delay.

It is important to note that despite the many statistically significant differences in swallow measures between the stroke and normal subjects in Groups 1 and 2, the stroke subjects in Group 1 were eating. This fact indicates that these swallow differences were not significant enough clinically to restrict oral intake. Interestingly, however, should one of these patients suffer a second stroke, a history of their eating after the first stroke would indicate that they returned to oral intake at 3 weeks post stroke. A different clinician seeing these patients at the time of their second strokes might interpret this information as an indication that these patients exhibited *normal* swallowing, when, in fact, their swallows were not normal, but were adequate to sustain safe and efficient oral intake. This may explain why after a second stroke, patients often exhibit more significant swallowing problems. Their CNS control of swallow was not normal after the first stroke, but was functional, and additional damage may further worsen their swallow physiology.

Stroke patients did not increase duration of airway closure as bolus volume increased as was observed in normal subjects in this study and previous work (Logemann et al., 1992). This may increase these patients' risk of aspiration on larger volumes, despite a decrease in pharyngeal delay times. Other modulations of swallow with increased bolus volume were observed in all subjects and are similar to previously reported systematic swallow changes with volume increases (Kahrilas et al., 1989; Logemann et al., 1992). Overall viscosity effects observed in all subjects were also similar to those previously reported.

In summary, bolus volume and viscosity appear to provide different sensory input for the swallow than cold, except on 1 ml volumes, in first-time stroke patients and in more dysphagic, neurologically impaired patients. It is important for the swallowing clinician to explore these differences during the radiographic study to identify optimal bolus types for each patient.

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Appendix

A diagram of the statistical analysis (3-way ANOVA) for Groups 1 and 2, indicating the further analyses that were completed when significant 3-way or multiple 2-way interactions were observed on any swallow measures (PRT, LAE, and LCPO), when significant group by bolus interactions occurred (PDT and LAC), and when there were no significant interactions (PSE, CPO, TBM, TBC).