ORIGINAL ARTICLE

The Effects of Lingual Exercise in Stroke Patients With Dysphagia

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ABSTRACT. Robbins JA, Kays SA, Gangnon RE, Hind JA, Hewitt AL, Gentry LR, Taylor AJ. The effects of lingual exercise in stroke patients with dysphagia. Arch Phys Med Rehabil 2007;88:150-8.

Objective: To examine the effects of lingual exercise on swallowing recovery poststroke.

Design: Prospective cohort intervention study, with 4- and 8-week follow-ups.

Setting: Dysphagia clinic, tertiary care center.

Participants: Ten stroke patients (n=6, acute: ≤3mo poststroke; n=4, chronic: >3mo poststroke), age 51 to 90 years (mean, 69.7y).

Intervention: Subjects performed an 8-week isometric lingual exercise program by compressing an air-filled bulb between the tongue and the hard palate.

Main Outcome Measures: Isometric and swallowing lingual pressures, bolus flow parameters, diet, and a dysphagia-specific quality of life questionnaire were collected at baseline, week 4, and week 8. Three of the 10 subjects underwent magnetic resonance imaging at each time interval to measure lingual volume.

Results: All subjects significantly increased isometric and swallowing pressures. Airway invasion was reduced for liquids. Two subjects increased lingual volume.

Conclusions: The findings indicate that lingual exercise enables acute and chronic dysphagic stroke patients to increase lingual strength with associated improvements in swallowing pressures, airway protection, and lingual volume.

Key Words: Deglutition; Cerebrovascular disease; Exercise; Rehabilitation; Therapeutics; Tongue.

DYSPHAGIA, OR DIFFICULTY swallowing, is a frequent consequence of stroke, estimated to occur in up to 76% of acute stroke patients.[1] In addition to the understandable impact of dysphagia on quality of life (QOL), swallowing problems also increase the risk for poststroke complications such as malnutrition, dehydration, and pneumonia. Pneumonia, perhaps the most serious health status sequela, accounts for at least 10% of poststroke deaths occurring within 30 days of hospital admission, a rate of incidence that conceivably is higher in the absence of treatment for acute swallowing problems.[1] Relatedly, patients with dysphagia after stroke frequently show significant aspiration,[2] eating dependency, and diminished rehabilitation potential[3] and require longer hospital stays and more frequent nursing home placements.[1] Despite this dire situation, evidence in support of the efficacy of specific interventions for stroke patients with swallowing problems is sparse.[4-6] Few of the available treatment programs are designed to directly rehabilitate the neurophysiologic underpinnings of dysphagia resulting from stroke. Instead, the current practice of dysphagia rehabilitation frequently relies on teaching the patient or a caregiver to enforce compensatory measures or behavioral strategies, such as dietary modifications or reduced bolus size. Such practices can negatively impact QOL and fail to promote an active patient role or capitalize on the neural basis of recovery poststroke. In contrast, intensive active exercise aims to enhance long-term motor rehabilitation by accessing neural plasticity, the basis of spontaneous, and therapy-induced recovery after stroke.

Swallowing is mediated by widely distributed sensorimotor neural circuitry that involves both cerebral hemispheres with corticobulbar tracts to the pons and medulla[7] interacting with the muscles of deglutition. Although disruption of this complex system centrally contributes to impaired swallowing, restoration of swallowing function after stroke may also depend, in part, on the recovery of neuromuscular morphologic factors such as muscle strength. To this end, optimal dysphagia rehabilitation relies on central neuroplastic modifications as well as peripheral increases in muscle mass and strength, which can be accomplished by challenging both systems with repetitive exercise.

The contribution of muscle strength to functional recovery after stroke has been shown in studies of the limb musculature. Improvements in functional activities such as timed stair climbing, walking, and chair rising have been shown in stroke subjects who perform strengthening exercises for the extremities.[8-11] However, the relation between oropharyngeal muscle strength and swallowing outcomes has received less attention. Robbins et al[12] reported positive changes in lingual strength after progressive resistance exercises for the tongue in healthy men and women over 70 years. These findings also included improvements in maximum lingual strength measured during the act of swallowing, suggesting direct carryover of isometric strength gains to functional swallowing outcomes. Evidence that healthy elders show a relation between lingual strength and pressures generated during dynamic swallowing motivates the explo-

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Table 1: Subject Demographics

Months Poststroke	Sex	Age (y)	Site of Lesion(s)	Residency
1†	Female	51	Left cerebellum; left medulla	Home
1*	Female	54	Right MCA territory	Home
1†	Female	60	Left postfrontal; right insula	Nursing home
1†	Female	90	Left cerebellum	Independent living facility
1*	Male	69	Left pons	Acute care, home
1†	Male	87	Left occipital, parietal, frontal cortices	Home
5†	Male	81	Left insula	Home
8†	Male	63	Left pons; right internal capsule	Home
48*	Male	59	Left pons; right cerebral peduncle	Home
>48†	Female	83	Left cerebral cortex (multifocal)	Nursing home

Abbreviation: MCA, middle cerebral artery.
*Subjects who completed the magnetic resonance imaging protocol.
†Subjects who completed the swallowing pressures protocol.

ration of the effects of lingual exercise on people with dysphagia secondary to the prevalent age-related condition of stroke.

The current study examines the hypothesis that patients with chronic or acute stroke who perform an 8-week progressive lingual resistance exercise program will increase lingual muscle strength, defined as isometric pressure generation. A second hypothesis is that as isometric lingual strength improves, subjects will spontaneously use greater lingual strength, or generate higher lingual pressures, when swallowing. Finally, the hypotheses will be explored that bolus flow parameters (duration, direction, clearance), dietary choices, and dysphagia-specific QOL measures will improve after the 8-week exercise protocol.

METHODS

Participants

This research was conducted with the approval of the Institutional Review Board of the University of Wisconsin Health Sciences Center and the Research and Development Committee of the William S. Middleton Memorial Veterans Hospital. A total of 10 ischemic stroke patients (n=6, acute: ≤3mo poststroke; n=4, chronic: >3mo poststroke) between the ages of 51 and 90 years (mean, 69.7y) participated in the study (table 1). After the initial baseline data-collection session, subjects were contacted by a swallowing team member (speech-language pathologist) by telephone or, when possible, in person during the initial week of the protocol and every 2 weeks thereafter for the 8-week duration.

Subjects were screened by using a health history questionnaire and were considered eligible for enrollment if they were 45 years of age or older; had a history of stroke; showed reduced lingual pressures with either the anterior or posterior tongue (defined as <40kPa based on a cohort of healthy older adults)[12,13]; and were referred by a physician for a videofluoroscopic swallowing evaluation that confirmed the presence of aspiration (material passes below the vocal folds), penetration (material enters the laryngeal vestibule but does not descend below the vocal folds), or oropharyngeal residue.

Exercise Regimen

All subjects performed an 8-week lingual exercise program consisting of compressing an air-filled bulb between the tongue and hard palate by using the Iowa Oral Performance Instrument (IOPI)[a] (fig 1). The IOPI is a handheld, portable pneumatic pressure sensor that provides visual feedback of pressure generation via an array of light-emitting diodes. Subjects exercised the anterior (operationally defined as 10mm posterior to the tongue tip) and posterior (operationally defined as 10mm anterior to the most posterior circumvallate papilla) portions of the tongue one after the other by performing 10 repetitions, 3 times a day on each of 3 days of the week as recommended for strength training by the American College of Sports Medicine.[14] These tongue locations were selected based on evidence of regional differences in lingual muscle composition, marked by a greater percentage of muscle tissue in the posterior tongue[15] that may respond differentially to exercise. Furthermore, differential use of the anterior and posterior tongue regions for pressure generation during swallowing have been documented,[16,17] warranting exploration of the effects of exercise at both tongue sites. The oldest stroke subject was unable to exercise the posterior tongue because of difficulty obtaining consistent placement of the bulb secondary to impaired oral sensorimotor control and therefore followed the exercise protocol for the anterior tongue only. Each participant maintained a daily log documenting the exercise activity.

Before beginning the exercise program, a baseline 1-repetition maximum (1-RM) pressure was identified. A 1-RM was defined as the highest amount (ie, pressure) that can be generated 1 time.[18] Each subject's maximum pressure was identified as the highest value from 2 sets of 3 trials, with the averages of

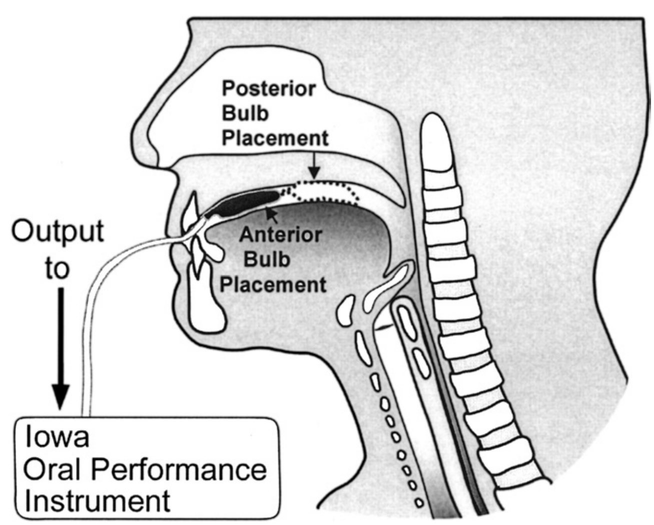

Fig 1. Positioning of air-filled IOPI pressure sensor between tongue blade and hard palate.

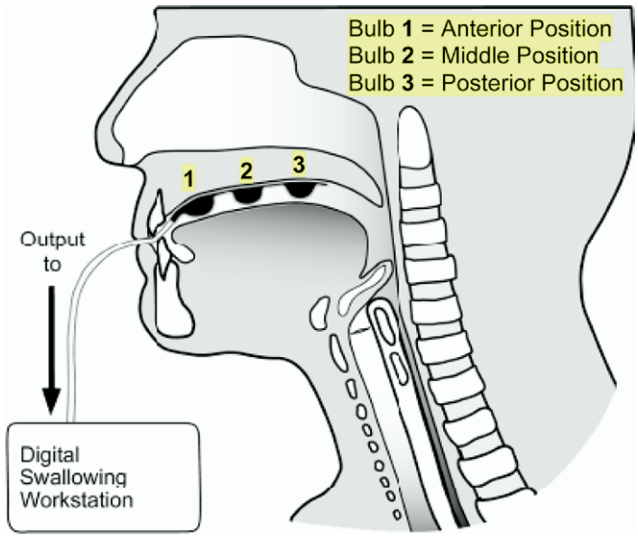

Fig 2. Positioning of 3-bulb array of pressure sensors for measuring swallowing pressures.

the sets differing by 5% or less to account for natural variability. Subjects exercised with a goal of 60% of the baseline maximum pressure for the first week of the program and 80% of the maximum pressure for the remaining 7 weeks. Each subject's maximum pressure was remeasured at the end of weeks 2, 4, 6, and 8, and the 80% exercise target was recalculated accordingly (table 2).

Data Collection

Data were collected at baseline (preintervention), week 4, and week 8 (postintervention).

Lingual Strength: Oral Pressure Sensor Instrumentation and Placement

Maximum isometric pressure. Lingual strength was measured via oral pressures generated against the IOPI air-filled bulb during an isometric resistance task. As performed during the exercise protocol, anterior and posterior tongue strength were measured with the IOPI bulb. Subjects were seated upright and asked to "press your tongue against the IOPI bulb as hard as possible." Two sets of 3 trials of maximum performance were collected for each tongue location.

Swallowing pressure. Lingual strength used for swallowing was measured via oral pressures generated during natural swallows performed for the videofluoroscopic swallow study. Pressures were obtained by using 3 air-filled bulbs (diameter, 13mm; spacing, 8mm) mounted on a silica strip. The strip was adhered longitudinally to the hard palate at midline with Stomahesive,[b] with the anterior bulb positioned at the alveolar ridge and the posterior bulb at the approximate junction of the hard and soft palates (fig 2). The bulbs were connected to a transducer suspended from the neck by a strap. Pressure data were sampled at a temporal resolution of .004 seconds (250Hz) and time linked to videofluoroscopic swallowing images by using the KayPentax Digital Swallowing Workstation.[c] Swallowing pressures were collected on a subset of 7 subjects (see table 1). One chronic stroke subject was unable to tolerate the 3-bulb array secondary to a hypersensitive gag reflex, and swallowing pressure data from 2 additional subjects did not record properly because of equipment malfunction.

Table 2: Exercise Target Value Calculation Schedule

Time Point	Exercise Target Value
Beginning of week 1	60% of baseline max
Beginning of week 2	80% of baseline max
End of week 2	Recalculate max; 80% of new max
End of week 4	Recalculate max; 80% of new max
End of week 6	Recalculate max; 80% of new max
End of week 8	Recalculate max for postintervention data collection

Table 3: Number of Subjects Completing and Swallows Completed During 3 Trials of Each Bolus Condition

No. of Subjects Completing 3 Trials of Each Bolus Condition	Baseline	Week 4	Week 8	Total Possible Subjects
3mL effortful	5	9	10	10
10mL liquid	4	7	10	10
3mL semisolid	7	8	9	10
3mL liquid	5	8	10	10
Total subjects completing all trials	4	7	9	10
No. of Swallows Completed for Each Bolus Condition	**Baseline**	**Week 4**	**Week 8**	**Total Possible Swallows**
3mL effortful	13	20	20	20
10mL liquid	17	26	30	30
3mL semisolid	23	28	29	30
3mL liquid	22	30	30	30
Total performed swallows	88	104	109	110

Bolus flow parameters: videofluoroscopic swallow studies. Videofluoroscopy was performed in the lateral view with the camera focused on the lips anteriorly, the pharyngeal wall posteriorly, the hard palate superiorly, and just below the upper esophageal sphincter (UES) inferiorly. At each of the 3 intervals (baseline, week 4, week 8) each subject performed a total of 11 swallows comprising 4 randomized bolus types: 3 swallows each of 3mL thin liquid, 10mL thin liquid, and 3mL semisolid and 2 effortful swallows of 3mL thin liquid. If a subject showed aspiration on 2 consecutive trials of a bolus condition, the condition was stopped and the next bolus condition in the randomization schedule was presented. Therefore, not all subjects completed the entire set of 11 swallows at each data-collection point (table 3). All 3-mL boluses were presented to participants via a spoon, and 10-mL boluses were administered via a catheter-tip syringe. During effortful swallow trials subjects were instructed to "swallow as hard as you can." Thin liquid boluses were Varibar Thin Liquid[d] (4 centipoise [cP] measured at a shear rate of $30s^{-1}$), and semisolid boluses were Varibar pudding[d] (5000cP measured at a shear rate of $30s^{-1}$). Varying bolus conditions were selected in light of the literature, which suggests that bolus volume and texture may modify the biomechanics, and hence the safety, of the swallow in some people.[17,19,20] Furthermore, effortful swallowing[21] was selected to examine whether lingual exercise has the potential to enhance one's ability to perform compensatory strategies that use greater lingual pressure generation than natural swallowing.

Magnetic resonance imaging. High-resolution anatomic images progressing from the anterior incisors to the posterior epiglottis were obtained by using a 1.5T GE magnetic imaging scanner (Signa LX)[e] and an 8-channel head coil. Coronal

T1-weighted fast spin-echo pulse sequence images were acquired with the following scan parameters: repetition time and echo time between pulses, 600ms and 23ms, respectively; field of view, 20cm; 26 coronal slice locations with 3-mm thickness and 0-mm skip; and matrix, 512×256 (yielding a spatial resolution of .39×.78mm). All subjects were instructed to touch their tongue tip to the edge of their lower front teeth and attempt to maintain that position during all of the scans. The duration of the longest individual scan was approximately 155 seconds. Magnetic resonance images were obtained on only 3 of the participants because of the artifact created by movement or the presence of dental crowns or other dental work, which distorted the clarity of the scans obtained from others and interfered with data measurement. Demographic information for the 3 subjects who completed the magnetic resonance imaging (MRI) protocol is provided in table 1.

QOL and dietary questionnaires. At all 3 data-collection intervals, subjects completed the SWAL-QOL questionnaire, a dysphagia-specific QOL instrument previously shown to be reliable and valid.[22] SWAL-QOL comprises 10 multi-item scales, 2 general scales, and a 14-item symptom battery that collects information from the patient's point of view.[23,24] In addition, a dietary intake questionnaire was administered. The dietary questionnaire was adapted from the normalcy of diet scale developed by List et al[25] with additional items from the Health Habits and History Questionnaire developed by Block et al[26] to represent a wide variety of foods and beverages (appendix 1).

Data Reduction

Lingual strength: maximum isometric pressure. The maximum isometric pressures obtained during 2 sets of 3 maximal lingual presses against the IOPI bulb with the anterior and posterior tongue were identified.

Lingual strength: swallowing pressure. Maximum swallowing pressures were calculated from swallowing pressure waveforms recorded at 3 bulb locations during bolus swallows recorded with videofluoroscopy. Pressure analysis extended from the time of onset of posterior bolus movement in the oral cavity until the bolus tail passed into the upper esophageal sphincter.

Bolus flow parameters: oropharyngeal residue measures. Postswallow barium contrast residue was judged from the videofluoroscopic image when the hyoid bone returned to rest, operationally defining the end of the swallow. Measurements were taken in the oral cavity, vallecula, posterior pharyngeal wall, piriform sinus, and upper esophageal sphincter. Ratings were scaled on a 3-point system, in which 0 corresponded to no barium residue, 1 to a coating of barium residue (a line of barium on a structure), and 2 to pooling of barium (an area larger than a line of barium on a structure). Those trials not performed because of the truncating of the videofluoroscopic oropharyngeal swallow study in subjects with severe dysphagia (see table 3) were automatically assigned a score of 2. An interjudge reliability of 84% and an intrajudge reliability of 90% agreement previously have been reported by using similar datasets.[21]

Bolus flow parameters: Penetration-Aspiration Scale. The 8-point Penetration-Aspiration Scale[27,28] was used to score each swallow observed during the videofluoroscopic swallowing evaluation. Scores on this scale reflect the occurrence, anatomic depth, subject response to, and clearance of material invading the laryngeal vestibule or trachea. Swallowing trials not performed because of the truncating of the videofluoroscopic oropharyngeal swallow study in subjects with severe dysphagia (see table 3) were automatically assigned a worst possible score of 8.

Bolus flow parameters: durational measures. To examine the effects of lingual strengthening on the duration of upper aerodigestive tract kinematics (hyolaryngeal excursion, UES opening) and bolus flow, timing measures were obtained by using standard criteria and definitions (table 4).[21,29,30]

Magnetic resonance imaging. Images were digitally transmitted to a dedicated laboratory computer, and a measure of total lingual volume was calculated by using Analyze software.[f] The muscles of interest (longitudinal, vertical, transverse, genioglossus, hyoglossus, styloglossus) were manually outlined for each slice of the full series of coronal tongue images. Tongue-slice areas automatically calculated for each slice by using the Analyze software were multiplied by the slice thickness to render measures of slice volume, which were summated to provide a total lingual volume. Mean interrater measurement error was determined to be 1.2% by repeating measures on 5 scans. Repeatability was established by obtaining 2 scans within 30 minutes of one another on a single healthy young subject, for which the percentage error of the total lingual volume was .22%.

QOL and dietary questionnaires. The SWAL-QOL subscales were scored by using Likert methods of summed ratings. Responses on the dietary intake questionnaire were extracted and analyzed for specific foods that were added to or eliminated from each subject's diet.

Statistical Analysis

Repeated-measures analysis of variance models were used to assess the impact of the 8-week lingual resistance exercise program on swallowing pressures measured using the 3-bulb array. Two-sample *t* tests were used to assess the impact of the

Table 4: Definitions of Durational Measures

Duration	Definition
Oral transit duration (OTD)	Time from beginning of posterior bolus movement until arrival of bolus head at ramus of mandible
Oral clearance duration (OCD)	Time from beginning of posterior bolus movement until arrival of bolus tail at ramus of mandible
Pharyngeal transit duration (PTD)	Time from arrival of bolus head at ramus of mandible until bolus head entering UES
Pharyngeal clearance duration (PCD)	Time from arrival of bolus head at ramus of mandible until bolus tail through UES
Pharyngeal response duration (PRD)	Time from beginning of hyoid excursion until hyoid returns to rest
Duration of hyoid maximum elevation (DOHME)	Time from first maximum hyoid elevation until last maximum hyoid elevation (duration hyoid remains maximally elevated before depressing)
Duration of hyoid maximum anterior excursion (DOHMAE)	Time from first maximum hyoid anterior excursion until the last maximum hyoid anterior excursion (duration hyoid remains maximally elevated in the anterior excursion position before depressing)
Duration to UES opening	Time from beginning of posterior bolus movement in oral cavity until UES opening
Duration of UES opening	Time UES opening until UES closed
Total swallowing duration (TSD)	Time from beginning of posterior bolus movement in oral cavity until hyoid returns to rest

Table 5: Change in Maximum Isometric Pressures (measured with the IOPI)

	Baseline		Week 4			Week 8		
Location	Mean Pressure (kPa)	95% CI	Mean Pressure (kPa)	95% CI	P	Mean Pressure (kPa)	95% CI	P
Anterior tongue	35.6	21.9–38.4	45.3	37.1–53.5	<.001*	51.8	43.6–60.0	<.001*
Posterior tongue	30.2	26.8–44.5	47.1	38.2–56.0	.01*	54.6	45.7–63.5	<.001*

Abbreviation: CI, confidence interval.
*Statistically significant.

8-week lingual exercise program on bolus flow parameters (residue, penetration and aspiration, duration) and isometric pressures measured by using the IOPI. Analyses of changes over time in swallowing pressures and bolus flow parameters were conducted separately for each trial. Models for swallowing pressure included bulb and visit as main effects. Separate models were fit for each follow-up visit. Analyses were conducted by using Proc Mixed in SAS.[g] A nominal *P* value of .05 was regarded as being significant, and 95% confidence intervals were calculated. A power analysis was not performed for this moderate sample, although it provides the pilot data from which power was calculated for a larger investigation of 200 dysphagic stroke subjects that is currently underway.

RESULTS

Lingual Strength

Maximum isometric pressure. There was a significant increase in maximum isometric pressures as measured by the IOPI at the anterior tongue site (week 4, $P<.001$; week 8, $P<.001$) and at the posterior tongue site (week 4, $P=.01$; week 8, $P<.001$) (table 5). A greater percentage of total gains were achieved during the initial 4 weeks of exercise for both tongue sites (63% anterior tongue; 76% posterior tongue).

Swallowing pressure. Maximum swallowing pressures increased significantly on at least 1 of 3 trials for 10mL liquid (week 4, $P=.04$; week 8, $P=.03$), 3mL liquid (week 4, $P=.04$; week 8, $P=.004$), and semisolid (week 4, $P=.05$; week 8, $P=.02$) bolus conditions after 4 and 8 weeks of exercise in those who completed these swallows at baseline (table 6).

Bolus Flow Parameters

Oropharyngeal residue measures. There was a significant reduction in overall residue for the 3-mL effortful swallow ($P=.02$), 10-mL liquid ($P=.02$), and 3-mL liquid ($P=.01$) bolus conditions, with the most significant changes occurring in pharyngeal residue ($P=.03$) (table 7). There was a trend toward reduction of average residue in the oral cavity ($P=.07$) and cricopharyngeus ($P=.09$) at week 8. No significant changes in average residue in the piriform sinuses ($P=.17$) or vallecula ($P=.14$) were observed after 8 weeks of exercise.

Penetration-Aspiration Scale. Penetration-Aspiration Scale scores were significantly reduced indicating increased swallowing safety for the 3-mL thin liquid bolus condition after only 4 weeks of exercise (week 4, $P=.02$; week 8, $P=.005$) and the 10-mL liquid bolus condition after the entire 8-week intervention (week 4, $P=.08$; week 8, $P=.003$) (fig 3). A trend toward reduced airway invasion also was observed for the effortful swallowing condition at week 8, which was statistically significant after 4 weeks of exercise (week 4, $P=.03$; week 8, $P=.07$). At the end of the 8-week exercise period, a greater number of subjects (9 subjects postexercise vs 4 subjects pre-exercise) was able to complete the entire videofluoroscopic oropharyngeal swallow study protocol (see table 3), indicating a reduced frequency of aspiration.

Durational measures. Postexercise, a significant decrease in the oral transit duration (time from beginning of posterior bolus movement until arrival of bolus head at ramus of mandible) for the 3-mL liquid bolus condition ($P=.036$) and an increase in the pharyngeal response duration (time from beginning of hyoid excursion until hyoid returns to rest) for both the 3-mL liquid ($P=.02$) and the l0-mL liquid $P=.024$) bolus conditions were observed on 1 of 3 trials in those subjects capable of performing these swallows at baseline (table 8).

Magnetic resonance imaging. Two of the 3 subjects who underwent MRI of the tongue showed increased lingual volume after 8 weeks of lingual exercise, with an average increase of 4.35%, well above the measurement error of 1.2%. The third subject showed a decline in lingual volume of 6.5%.

QOL and dietary outcomes. Average SWAL-QOL scores increased for all subscales with statistically significant changes in the areas of fatigue, communication, and mental health. Substantial gains also were made in the burden and social subscales (table 9). Dietary intake questionnaires indicated at

Table 6: Change in Maximum Swallowing Pressures (measured with the 3-bulb array)

Trial	Bolus Condition	Baseline Mean (mmHg)	Change (baseline to week 4)	P	Change (baseline to week 8)	P
A	3mL effortful	155.72	8.51	.71	8.27	.62
B	3mL effortful	146.41	47.04	.10	8.32	.53
A	10mL liquid	53.43	36.56	.04*	51.78	.03*
B	10mL liquid	57.48	12.59	.35	47.75	.07
C	10mL liquid	56.42	17.07	.16	41.40	.20
A	3mL semisolid	91.03	45.14	.05*	35.08	.02*
B	3mL semisolid	100.14	47.78	.02*	35.28	.06
C	3mL semisolid	123.14	10.46	.57	29.19	.14
A	3mL liquid	84.29	20.39	.16	43.27	.04*
B	3mL liquid	68.58	47.28	.04*	73.02	.004*
C	3mL liquid	118.17	−4.38	.84	0.68	.97

*Statistically significant.

Table 7: Change in Mean Oropharyngeal Residue Scale Scores After 8 Weeks of Exercise

Trial	Bolus Condition	Change	*P*	Change	*P*	Change	*P*
		Cricopharyngeus		Oral Cavity		Pharyngeal Wall	
A	3mL effortful	−0.9	0.03*	−0.7	.05*	−0.3	.38
B	3mL effortful	−0.7	0.11	−0.8	.04*	−0.8	.07
A	10mL liquid	−0.4	0.22	−0.3	.43	−0.8	.04*
B	10mL liquid	−0.4	0.31	−0.6	.10	−1.1	.007*
C	10mL liquid	−0.8	0.08	−0.6	.05	−1.2	.003*
A	3mL semisolid	−0.4	0.27	−0.4	.17	−0.9	.04*
B	3mL semisolid	−0.4	0.22	−0.3	.32	−0.3	.28
C	3mL semisolid	−0.2	0.45	−0.2	.51	−0.3	.20
A	3mL liquid	−0.2	0.17	−0.4	.13	−0.2	.45
B	3mL liquid	−0.4	0.22	−0.4	.22	−0.6	.10
C	3mL liquid	−0.8	0.10*	−0.8	.008*	−1.0	.02*
	Average	−0.5	0.09	−.05	.07	−0.7	.03*
		Piriform Sinus		Vallecula		Overall	
A	3mL effortful	−0.2	0.45	−0.2	.58	−0.5	.09
B	3mL effortful	−0.7	0.05*	−0.7	.02*	−0.7	.02*
A	10mL liquid	−0.3	0.20	−0.1	.70	−0.4	.15
B	10mL liquid	−0.3	0.41	−0.3	.39	−0.6	.05
C	10mL liquid	−0.7	0.05*	−0.2	.47	−0.7	.02*
A	3mL semisolid	0.1	0.79	−0.4	.27	−0.4	.18
B	3mL semisolid	0.0	1.00	−0.4	.17	−0.3	.07
C	3mL semisolid	−0.1	0.59	−0.3	.20	−0.2	.14
A	3mL liquid	0.0	1.00	−0.4	.17	−0.3	.07
B	3mL liquid	−0.2	0.35	−0.6	.10	−0.4	.10
C	3mL liquid	−0.8	0.02*	−0.7	.08	−0.8	.01*
	Average	−0.3	0.17	−0.4	.14	−0.5	.04*

*Statistically significant.

baseline that 8 of the 10 subjects reported the elimination of specific foods or beverages from their diets, whereas the remaining 2 subjects were eating a general diet with compensatory strategies at baseline. Six subjects, including the oldest (90y) and youngest (51y) acute stroke subjects, reported the addition of difficult-to-swallow food items, such as nuts, popcorn, salad, and raw vegetables, to their diets as they progressed through the strengthening regimen. Qualitative SWAL-QOL comments revealed reports of decreased coughing on liquids, dietary upgrades, and an improved ability to use supplemental compensatory strategies (ie, supraglottic swallow) by both chronic and acute stroke subjects. A number of patients commented that they enjoyed the sense of participation in their recovery this active regimen provides.

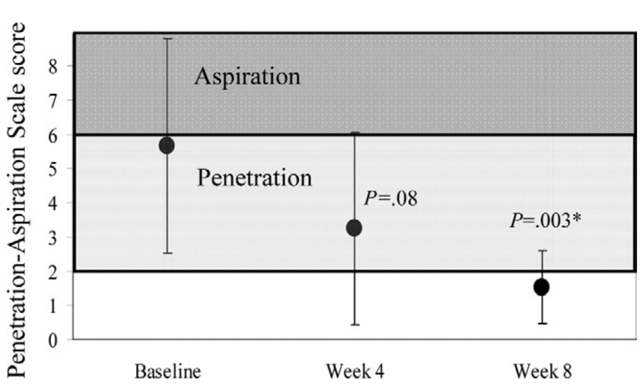

Fig 3. Change in mean score on the Penetration-Aspiration Scale for the 10mL liquid bolus condition. Legend: ●, mean score for 10mL liquid bolus condition. *Statistically significant.

DISCUSSION

The primary finding of this study is that stroke patients with dysphagia are able to improve lingual strength with an 8-week program of isometric resistance exercises for the tongue, as evidenced by a continuous increase in isometric lingual pressure generation throughout the duration of the protocol.

Second, these dysphagic stroke patients used greater lingual strength during swallowing naturally as shown by higher swallowing pressures in 3 of 4 bolus conditions postintervention, despite performing only isometric exercises, not dynamic swallowing exercises, during the 8-week study duration (ie, subjects spontaneously generated greater *swallowing* pressures when swallowing thin liquid and semi-solid boluses after 8 weeks of *isometric* exercise) (see table 6).

A third important finding is that this cohort of stroke patients improved bolus flow kinematics marked by reduced oropharyngeal residue and decreased airway invasion associated with faster oral transit times and longer pharyngeal response durations (representing the time that the airway is protected) for liquid swallows. In addition, 90% of the subjects were able to safely perform the entire videofluoroscopic oropharyngeal swallow study postexercise, compared with 40% pre-exercise, indicating an overall improvement in the frequency of aspiration and bolus clearance across bolus consistencies. The literature indicates that elderly people are most at risk for liquid aspiration, and links to pneumonia are becoming clear.[2] Thus, it is most clinically significant that the proposed exercise intervention enhanced airway protection for swallowing liquids,

Table 8: Percentage Change in Durational Measures After 8 Weeks of Exercise

Trial	Bolus Condition	% Change	P	% Change	P	% Change	P	% Change	P
		OTD		OCD		PTD		PCD	
A	3mL effortful	0.10	.97	0.11	.84	0.11	.90	0.10	.93
B	3mL effortful	0.12	.77	0.14	.33	0.08	.52	0.09	.82
A	10mL liquid	0.09	.76	0.10	.93	0.13	.11	0.10	.76
B	10mL liquid	0.09	.92	0.11	.76	0.11	.72	0.10	.76
C	10mL liquid	0.10	.99	0.11	.80	0.14	.57	0.09	.76
A	3mL semisolid	0.06	.33	0.07	.52	0.08	.75	0.08	.71
B	3mL semisolid	0.04	.13	0.06	.26	0.13	.39	0.12	.44
C	3mL semisolid	0.07	.52	0.08	.80	0.16	.17	0.15	.16
A	3mL liquid	0.05	.036*	0.07	.50	0.12	.74	0.11	.74
B	3mL liquid	0.08	.59	0.36	.20	0.14	.59	0.14	.53
C	3mL liquid	0.12	.38	0.12	.44	0.12	.80	0.10	.97
		PRD		DOHME		DOHMAE		TSD	
A	3mL effortful	0.11	.46	0.07	.42	0.11	.71	0.12	.51
B	3mL effortful	0.11	.39	0.08	.52	0.09	.64	0.12	.24
A	10mL liquid	0.09	.55	0.09	.86	0.10	.94	0.10	.96
B	10mL liquid	0.13	.30	0.14	.20	0.14	.53	0.11	.52
C	10mL liquid	0.12	.024*	0.08	.73	0.11	.78	0.12	.37
A	3mL semisolid	0.09	.23	0.20	.38	0.14	.21	0.07	.43
B	3mL semisolid	0.10	.99	0.14	.14	0.11	.80	0.07	.26
C	3mL semisolid	0.11	.25	0.09	.48	0.17	.17	0.08	.57
A	3mL liquid	0.12	.020*	0.11	.74	0.21	.17	0.09	.73
B	3mL liquid	0.11	.16	0.09	.28	0.13	.29	0.13	.42
C	3mL liquid	0.11	.38	0.15	.46	0.11	.88	0.12	.058

Abbreviations: See table 4.
*Statistically significant.

the consistency most commonly aspirated in older adults. Furthermore, withholding or altering liquids to prevent aspiration often occurs at the expense of satisfying fluid needs in the older population for whom dehydration is prevalent and detrimental. To this end, the capacity of exercise to empower this group of patients to safely swallow unrestricted liquids may have implications for improved hydration in elders poststroke as well as improved QOL related to selecting all fluids they desire. Our findings of reduced aspiration of small and large liquid bolus volumes may relate to our observations of a prolonged pharyngeal response postexercise, which includes laryngeal closure, thereby providing airway protection.[31] In the presence of an increase in lingual strength, the longer pharyngeal response duration may relate to the observed reduction in pharyngeal residue as hyoid elevation augments UES pressure reduction and increased UES opening, thereby enabling bolus clearance into the esophagus.[31] Such changes in biomechanic events likely relate to dietary enhancements because all of the 5 subjects who reported the elimination of small particles of food, such as corn, nuts, and ground beef, from their baseline diets reported eating these items after the exercise program.

Although it is clear that the lingual-strengthening program resulted in enhanced swallowing function including improved airway protection, it remains less clear if these results reflect changes at the muscle level alone or neuroplastic modifications as well. Evidence that a subset of subjects increased total lingual volume suggests that strengthening may increase muscle size and mass, thereby building a stronger foundation for

Table 9: Mean SWAL-QOL Subscale Scores

SWAL-QOL	Baseline	Week 4	Week 8	Change (baseline to week 8)	95% CI	P
Fatigue	40	55	58	18	0 to 35	.047*
Sleep	71	73	75	4	−11 to 19	.58
Burden	49	55	79	30	−1 to 61	.053
Desire	56	70	80	24	−6 to 54	.10
Duration	39	50	65	26	−12 to 65	.15
Physical	64	63	72	8	−7 to 23	.24
Selection	55	45	68	13	−23 to 48	.43
Communication	53	61	72	19	3 to 35	.026*
Fear	71	69	79	8	−8 to 23	.28
Mental	49	68	80	31	6 to 56	.022*
Social	55	72	79	24	−6 to 54	.098

NOTE. Maximum score per subscale is 100.
*Statistically significant.

performing skilled movements. However, the observed carryover of postexercise isometric pressures into stronger pressures observed during the complex task of swallowing also may reflect neuroplastic changes associated with alterations in motor function. For instance, it may be that a stronger oral phase facilitates the necessary sensorimotor stimuli to "trigger" a more efficient pharyngeal swallow response. Support of the notion of the ability of exercise to facilitate neuroplasticity comes from the fact that this group of stroke subjects showed more than 60% of their overall improvement in isometric lingual pressure after only 4 weeks of exercise, although they continued to increase strength for the remaining 4 weeks of the program (see table 5). Corresponding positive changes in swallowing pressures and Penetration-Aspiration Scale scores after only 4 weeks of exercise suggest that changes in the dynamic aspects of pressure generation and airway protection also improved primarily during the early stages (ie, first 4wk) of exercise. It has been proposed that improvements in a subject's performance on strength-dependent tasks occurring within the initial 4 weeks of an exercise program reflect changes in underlying neuromuscular control, whereas subsequent enhanced performance results from muscle hypertrophy and more sustainable changes in muscle strength, mass, and volume.[32] Thus, the initial rise in pressure generation and reduction in aspiration found after 4 weeks of exercise in these stroke subjects may reflect changes in the neural underpinnings of swallowing, whereas their later improvements in lingual strength and associated outcomes at 8 weeks implicate the positive effects of the intervention on the contributing morphologic deficits.

The increase in lingual volume shown by 2 of the 3 subjects who completed the MRI portion of the protocol suggests that muscle hypertrophy may be a second factor underlying the findings of improved swallowing function. The decline in lingual volume observed in the third subject may relate to his self-reported reduced oral intake and depression during the initial weeks of the exercise protocol. At baseline, this subject reported a "worse than usual" appetite on the dietary questionnaire and scores of 0 (lowest possible score) on the eating burden, eating desire, and social scales of the SWAL-QOL. Although nutritional and caloric intake were not quantified in this study, it is conceivable that this patient's limited appetite, depression, and disinterest in eating resulted in a reduction in muscle volume during the study period that was not reversed by only 8 weeks of strengthening. It is possible that a longer exercise period is necessary to induce muscle hypertrophy in some patient groups. Future work is warranted and underway on a larger group of stroke patients to distinguish the effects of exercise dose on the multivariate central and peripheral factors contributing to swallowing control.

Additional work also is necessary to differentiate specific swallowing profiles in groups of stroke patients with various sites and/or sizes of lesions, thereby predicting for whom the intervention will be most effective. Although 4 chronic stroke subjects showed improved lingual strength for isometric and swallowing tasks, interpretation of the findings from the current study must be undertaken with caution because of the enrollment of 60% of subjects during the period of acute motor recovery that occurs within the first 3 months poststroke.[33-35] There is evidence in the rehabilitation literature that a critical time period for intervention poststroke may exist and that certain interventions may be most effective when initiated within days postinfarct.[36] On the other hand, the spontaneous neural recovery occurring in the early period poststroke may preclude or even interfere with rehabilitative efforts. Thus, it is of interest to contrast outcomes in acute and chronic stroke subjects relative to a control group to determine the optimal timing of intervention. Despite the absence of a control group and the small sample size, these findings warrant continued focus on larger subject groups and time-dependent outcomes.

Finally, improved safety with effortful swallowing, as evidenced by reduced residue in all locations of the oropharynx and a trend of reduced airway invasion, was observed in the absence of increased swallowing pressures. These findings are in contrast to those shown by healthy older adults who showed an increase in swallowing pressures with effortful swallowing after completing the same 8-week exercise protocol.[12] Because those previously documented subjects were healthy, nondysphagic adults, there was no residue or airway invasion present at baseline to be modified by the intervention. Improved swallowing safety for dysphagic patients, in the absence of increased swallowing pressures seen with the healthy exercisers, indicates that the exercise regimen modified additional underlying physiologic and biomechanic parameters not clearly accounted for by the measures obtained in this study. Future efforts to clarify specific physiologic and biomechanic parameters of effortful swallowing may elucidate the contributions of isometric exercise to effortful swallowing enhancement in various subject groups.

CONCLUSIONS

Acute and chronic stroke patients alike with dysphagia show positive changes in lingual strength after performing 8 weeks of progressive resistance lingual exercises. Improved isometric strength corresponded with spontaneous increased pressure generation during swallowing despite the fact that the coordinated, functional act of swallowing was not practiced.

The patients enrolled in this study showed a significant improvement in swallowing function and dysphagia-specific QOL measures, with reported changes in their social lives and dietary intake. This evidence that subjects with poststroke dysphagia not only are capable of performing and benefiting from lingual exercise but also are enthusiastic about this intervention as a complement to standard treatment provides the grounds for consideration of active exercise, when performed safely and judiciously, as an innovative and critical component to the standard dysphagia treatment of stroke patients.

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APPENDIX 1: SAMPLE QUESTION FROM DIETARY INTAKE QUESTIONNAIRE

Clinician: I'd like you to tell me if you've eliminated any of the following foods from your diet due to your swallowing problem:

Raw carrots/celery	Dry bread/crackers	Peanuts	Corn/Peas
Meat	Popcorn	Water/Coffee/Other Thin Liquids	

Is there anything else you would like to eat that you are unable to at this time due to your swallowing problem?____

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