Temporal and Biomechanical Characteristics of Oropharyngeal Swallow in Younger and Older Men

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Text

As the U.S. population ages, there is increasing need for data on the effects of aging in healthy elderly individuals over age 80. This investigation compared the swallowing ability of 8 healthy younger men between the ages of 21 and 29 and 8 healthy older men between the ages of 80 and 94 during two swallows each of 1 ml and 10 ml liquid. Videofluoroscopic studies of these swallows were analyzed to confirm the absence of swallowing disorders. Biomechanical analysis of each swallow was completed, from which data on temporal, range of motion, and coordination characteristics of the oropharyngeal swallow were taken. Position of the larynx at rest, length of neck, and pattern of hyoid bone movement were also compared between the two groups. None of the younger or older men exhibited any swallowing disorders. The C2 to C4 distance of older men was significantly shorter than that of younger men, and laryngeal position at rest was lower than in younger men but not significantly so. Older men had a significantly longer pharyngeal delay than younger men and significantly faster onset of posterior pharyngeal wall movement in relation to first cricopharyngeal opening. The older men exhibited significantly reduced maximum vertical and anterior hyoid movement as compared to the younger men even when accounting for the difference in C2 to C4 distance in older men. These data support the hypothesis of reduced muscular reserve in the swallows of older men as compared to younger men. Older men also exhibited less width of cricopharyngeal opening than younger men at 10 ml volume, indicating less upper esophageal sphincter flexibility in the swallows of older men. The potential for exercise to improve reserve is discussed. Significant changes in extent of hyoid elevation and duration of cricopharyngeal opening were seen as liquid bolus volume increased.

KEY WORDS: normal aging, swallowing, videofluoroscopy, biomechanical analysis, volume

Adults over 60 years old with no history of cardiovascular, gastrointestinal, skeletal, head and neck, or neurological disorders have been shown to exhibit general differences in body structure and specifically swallowing physiology from younger adults of the same sex (Rademaker, Pauloski, Colangelo, & Logemann, 1998; Robbins, Hamilton, Lof, & Kempster, 1992; Tracy et al., 1989). General structural changes that occur with age include reduced muscle mass, reduced physical stature, reduced bone mass, and an increase in adipose tissue (Kenney, 1985). There is a general slowing in performance of gross and fine motor tasks and slowed reaction times (Welford, 1984, 1988)—perhaps related

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to reduced conduction velocity in aging nerve fibers (Kenney, 1985). Stature diminishes with age at a rate of 1 cm per decade (Miall et al., 1967). This change is attributed to loss of foot arches, an increase in spinal curvature, and a true shortening of the vertebral column because connective tissue of the intervertebral disks dries out (Kenney, 1985).

Changes in deglutition seen with normal aging include significantly slower oral transit times (Sonies, Baum, & Shawker, 1984), a significantly longer delay in triggering the pharyngeal swallow (Ades, Ballor, Shikaga, Utton, & Nair, 1996; Logemann, 1990; Rademaker et al., 1998; Robbins et al., 1992; Sonies, Parent, Morrish, & Baum, 1988; Tracy et al., 1989), and a significantly slower pharyngeal contraction wave during the pharyngeal stage of swallow. In a study of lingual pressure generation, Robbins, Levine, Wood, Roecker, and Luschei (1995) found reduced lingual isometric pressures in older male subjects (ages 67–83) as compared to younger subjects (ages 22–33). Peak swallowing pressures were the same for the two groups. These authors commented that overall lingual pressure reserve (defined as maximum isometric pressure to swallowing pressure within each subject) declines with age and that illness may increase the older patient's risk for dysphagia. These findings have been attributed to reduced muscle mass (Campbell, McComas, & Petito, 1973) and changes in the density of muscle fibers (Dayan, Abrahami, Buchner, Gorsky, & Chimovitz, 1988; Fanous, 1987; Newton, Abel, Robertson, & Yemm, 1987; Price & Darvell, 1981; Rastatter, McGuire, Bushong, & Loposky, 1987).

Small amounts of pharyngeal residue, greater than that seen in younger adults, have been reported in the elderly (Cook et al., 1994; Dejaeger, Pelemans, Ponette, & Joosten, 1997; Ekberg & Feinberg, 1991) and have been found to result from reduced tongue driving force (Dejaeger et al., 1997). Taste and smell sensitivity decreases with age (Doty et al., 1984; Weiffenbach, Baum, & Burghauser, 1982). These physiologic changes in sensation and deglutition have been attributed to several factors: aging effects on structure, including muscle composition and ligaments, and changes in the timing of central neural processing and in the sensitivity of peripheral receptors (Robbins et al., 1992). Lovat (1996) reports that aging also causes a decrease in gastrointestinal reserve, making older individuals more sensitive to minor insults so that decompensation can rapidly occur.

Reduced functional reserves in motor performance is a phenomenon that has been repeatedly emphasized throughout the literature on normal aging (Buchner & Wagner, 1992; Kenney, 1985). Reserve is defined as the difference between the extent of movement needed to accomplish a task and the extent of movement actually used. Reserve of function is used to cope with physical activity or challenge to the mechanism above the individual's resting state, such as illness (Buchner & Wagner, 1992; Johnson, 1993; Kenney, 1985; Troncale, 1996). As Kenney (1985) points out in defining the concept of reserve, when a 30-year-old and a 70-year-old are sitting together, little distinguishes their internal state, but ask them to be active and differences are usually apparent.

The vast majority of the investigations examining age effects on swallowing have examined individuals under 80 years old and have used only temporal measures of swallow. There is need to study the temporal and biomechanical (extent of structural movement over time) characteristics of swallow in healthy subjects over age 80 and to compare these measures to those of younger, normal, healthy adults of the same sex. This present investigation compares certain temporal and biomechanical characteristics of swallows produced by healthy younger (20–29) and older men (80–94).

Method

Subjects

Eight healthy younger men between the ages of 21 and 29 and eight healthy older men between the ages of 80 and 94 served as subjects for this study, which was approved by the Institutional Review Board of Northwestern University. Recruitment was through advertisements. Only men were included in this study because of the greater prominence of their thyroid cartilage and our interest in hyolaryngeal movement during swallow. None of these individuals had any history of a swallowing problem or of any illnesses, diseases, injuries, medications, or surgeries involving head and neck, central nervous system, musculoskeletal system, or the gastrointestinal tract that might affect swallowing. All were living independently.

Data Collection and Reduction

Each subject underwent a radiographic study of oropharyngeal swallowing. The protocol for the radiographic studies of each subject involved presentation of two swallows each of 1 ml and 10 ml liquid barium. These bolus volumes were selected because their comparison allows assessment of volume effects on swallow. During each videofluorographic study, the fluoroscopic tube focused on the tongue tip anteriorly, the pharyngeal wall posteriorly, the soft palate superiorly, and the 7th cervical vertebra inferiorly. A penny was taped under the chin of the subjects at midline to serve as a "ruler" to compensate for radiographic magnification during the biomechanical analysis. Videofluorographic studies were recorded on 3/4-inch videotape, with timing information encoded onto each frame to facilitate later frame-by-frame, slow motion examination to identify and define any possible swallowing disorders and computer biomechanical analysis.

Each subject's videofluorographic study was first analyzed in slow motion to define any swallowing disorders—that is, visible swallowing abnormalities in bolus flow or structural movements displayed on each swallow. Timing and etiology of any aspiration and the presence of residue in the oral cavity on the pharyngeal walls, in the valleculae, or in the pyriform sinuses were noted and rated as *none, mild, moderate,* or *severe.*

A biomechanical analysis of the pharyngeal swallow in these subjects was completed on their two 1-ml and two 10-ml liquid swallows. Each video frame (1/30 s intervals) from each of the swallows of liquid was digitized, using an IBM-compatible 80486 computer equipped with a Data Translation Image Digitizing Board (Data Translation Frame Grabber, model DT 2861) with interactive software (Logemann, Kahrilas, Begelman, & Pauloski, 1989; Pauloski, Logemann, Fox, & Colangelo, 1995). For biomechanical analysis, an anchor point, an angle measuring subject's head tilt relative to true vertical, and a reference distance are marked on each frame and used in conjunction to control for subject's head and body movement in the vertical, A-P, and horizontal planes as well to measure absolute distance of structural movement during the swallow. An anatomical structure that will be stable during the swallow is chosen as the anchor point. When measuring events in the pharyngeal swallow, the anterior-inferior corner of C4 is routinely used as the anchor point. The angle of the subject's head tilt from true vertical is also measured along the anterior surface of the cervical vertebrae. The reference distance is a line usually marked along a structure or item of known length. In this study a penny taped to the subject's chin was used as the reference distance (18 mm).

On each marked video frame, the anchor point is adjusted to become the origin of the coordinate system by subtracting its actual x and y pixel values from each point in the digitized image. In this manner, the anchor point on each frame always has the adjusted coordinates of (0, 0), regardless of how much a subject might move in any plane. The subject's postural angle is also used to virtually rotate each individual digitized image so that the subject's head tilt is mathematically in line with true vertical. This adjustment simplifies calculation of anterior and vertical movement of structures and assures that structural movement is calculated relative to the vertebral column. Finally, the reference distance is used to scale the marked points to actual size in mm. Because the reference distance is marked on each digitized image, it also adjusts for any movement the subject might make during the study toward or away from the fluoroscope and corrects for differences in fluoroscopic magnification during the swallow. Structures of interest are then marked and calculated relative to the anchor point, angle of head tilt, and reference distance. For further information on scaling and rotating of marked images, see Logemann et al., 1989.

In this study, the following points, lines, and angles were marked on each digitized video frame: (1) a point on the anterior-inferior corner of C4, which served as the anchor point; (2) a line along the length of a penny taped under the subject's chin to serve as the reference distance; (3) the angle of the subject's head tilt from true vertical, measured from the anterior-inferior aspect of C4 to the anterior-inferior corner of C2; (4) a line between the anterior and posterior walls of the cricopharyngeal region approximately 5 mm below the under surface of the true vocal folds to represent cricopharyngeal opening; (5) a point on the posterior-superior corner of the subglottic air column to represent laryngeal movement; (6) a line from the anterior-superior tip of the arytenoid to the point on the posterior surface of

Figure 1. Tracing of a lateral view from one videofluoroscopic frame of a swallow study with marked points, lines, and angles identified, including (1) anterior-inferior corner of C4; (2) length of reference marker (penny); (3) postural angle; (4) anterior and posterior walls of the cricopharyngeal region; (5) posterior-superior corner of the subglottic air column; (6) anterior-superior tip of the arytenoid to the point opposite on posterior epiglottis; (7) anterior-inferior corner of C2 to the tongue base and a point on the posterior pharyngeal wall at that level; and (8) most anterior-superior aspect of the hyoid bone.

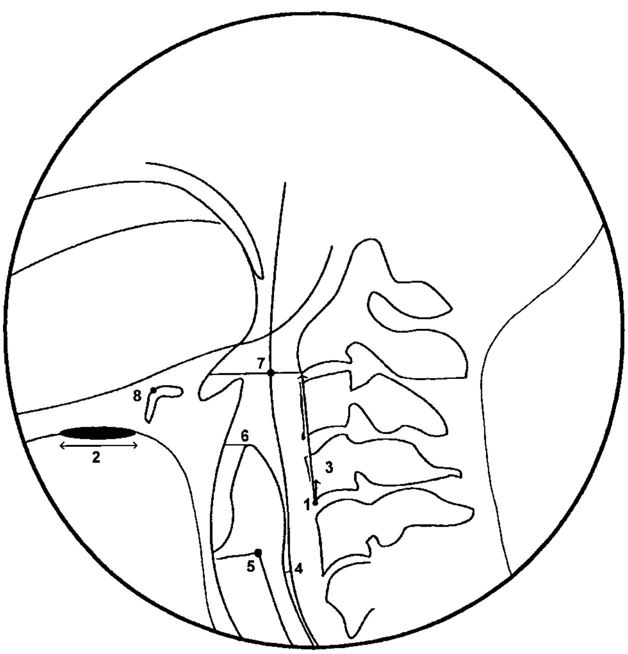


Table 1. Pearson correlation coefficients for inter- and intrajudge reliability measures for biomechanical analysis.

Measure	Interjudge	Intrajudge
BOT to PPW contact	.94	.94
Anterior hyoid movement	.94	.90
Vertical hyoid movement	.98	.98
Anterior laryngeal movement	.89	.98
Vertical laryngeal movement	.90	.97
Laryngeal closure	.94	.94
Cricopharyngeal opening	.95	.99

the epiglottic base immediately anterior to the arytenoid to represent laryngeal closure at the vestibule; (7) a line from the anterior-inferior corner of C2 to a point on the posterior pharyngeal wall and a point on the tongue base at that level to measure posterior tongue base movement and anterior movement of the posterior pharyngeal wall; and (8) a point on the most anterior-superior aspect of the hyoid bone to represent hyoid movement. These measures are illustrated in Figure 1.

In order to assess reliability of measurement, six randomly selected swallows (10% of all 64 swallows in this study) were completely re-marked by the same research assistant and by a second research assistant. Reliability of measurement assessed with Pearson correlation coefficients ranged from .90 to .99 for intrajudge and .89 to .98 for interjudge reliability. Maximum difference between re-markings was 1 mm for interjudge reliability on laryngeal elevation. Table 1 summarizes the Pearson correlation coefficients for the re-marked swallows.

Computer software calculated the coordinate values of each point marked on each video frame and stored these for later analysis. Distance-over-time plots of the movement of each selected anatomic point throughout each swallow were then produced. Twenty-three measures were taken from the data points on these plots, as listed in Table 2.

1–4 Duration measures (in s): (1) pharyngeal delay (time from the bolus head reaching the point where the lower edge of the mandible crosses

Table 2. Measures taken from the data points on the distance-over-time plots of each swallow.

Categories of measurement	Measures
Duration measures (in s)	1. Pharyngeal delay 2. Base of tongue contact to posterior pharyngeal wall 3. Cricopharyngeal opening 4. Laryngeal closure
Onset of movement measures in relation to first frame indicating cricopharyngeal opening (in s)	5. Onset of base of tongue posterior movement at the level opposite the anterior inferior corner of the 2nd cervical vertebra 6. Posterior pharyngeal wall movement anteriorly at the level of the anterior inferior corner of the 2nd cervical vertebrae 7. Laryngeal closure 8. Vertical laryngeal movement 9. Bolus arrival at the upper pyriform sinuses
Extent of structural movement (in mm) in relation to first frame indicating cricopharyngeal opening	10. Laryngeal elevation 11. Anterior laryngeal movement 12. Hyoid elevation 13. Anterior hyoid movement
Time (in s) from first frame indicating cricopharyngeal opening to maximal opening	14. Single variable defined at left
Maximal extent of structural movement (in mm)	15. Base of tongue movement at anterior-inferior corner of C2 16. Anterior movement of the posterior pharyngeal wall at inferior C2 17. Cricopharyngeal opening 18. Posterior movement of the epiglottic base at the level of the superior tip of the arytenoid 19. Anterior movement of the superior tip of the arytenoid cartilage 20. Laryngeal elevation 21. Anterior laryngeal movement 22. Anterior hyoid movement 23. Vertical hyoid movement

the tongue base until the first laryngeal elevation in the swallow is seen); (2) base of tongue contact to the posterior pharyngeal wall; (3) cricopharyngeal opening; and (4) laryngeal closure.

5–9 Onset of movement measures (in s) in relation to the first frame indicating cricopharyngeal opening: (5) onset of base of tongue posterior movement at the level opposite the anterior inferior corner of the 2nd cervical vertebra; (6) posterior pharyngeal wall movement anteriorly at the level of the anterior inferior corner of the 2nd cervical vertebrae; (7) laryngeal closure; (8) vertical laryngeal movement; (9) bolus arrival at the upper pyriform sinuses.

10–13 Measures of extent of structural movement (in mm) in relation to the first frame indicating cricopharyngeal opening: (10) laryngeal elevation; (11) anterior laryngeal movement; (12) hyoid elevation; and (13) anterior hyoid movement.

14 Time (in s) from first frame indicating cricopharyngeal opening to maximal opening

15–23 Maximal extent of structural movement (in mm) including (15) base of tongue movement at anterior inferior corner of C2; (16) anterior movement of the posterior pharyngeal wall at inferior C2; (17) cricopharyngeal opening; (18) posterior movement of the epiglottic base at the level of the superior tip of the arytenoid; (19) anterior movement of the superior tip of the arytenoid cartilage; (20) laryngeal elevation; (21)anterior laryngeal movement; (22) anterior hyoid movement; and (23) vertical hyoid movement.

All measures of structural movement (10–13 and 15–23) begin with the videoframe showing first movement and end with the videoframe exhibiting last movement. Laryngeal position was measured at rest in relation to the anterior inferior corner of the second cervical vertebra. The distance between the anterior superior corner of C2 and the anterior inferior corner of C4 was measured as a representation of neck length. Pattern of hyoid bone movement from its rest position to maximal elevation and back to rest was plotted during each swallow.

Statistical comparisons between the younger and older men were made using ANOVA (SAS Institute, Inc.) with factors for age and volume. The two trials for each subject on each bolus volume were kept distinct in the statistical analysis. For variables with a significant interaction between age and volume, comparisons were made separately for each volume or age group. For variables with no interaction between age and volume, comparison of age groups were made by averaging across the two volumes. To account for neck length, a separate similar analysis was completed using neck length as a covariate. For the volume comparison, variables with no interaction were averaged across the age groups. Independent sample *t* tests were used to compare laryngeal position and neck length for younger and older men.

Results

None of the healthy younger or older men exhibited any swallowing disorders. None exhibited any aspiration or penetration. Residue was ranked as none or mild for all subjects in both age groups. Mild residue was noted more often in older men. Younger men usually exhibited no residue. Differences in the measures of duration, coordination, and extent of structural and bolus movement for the younger and older men are presented in Table 3. The distance between the anterior superior corner of the second cervical (C2) vertebra and the anterior inferior corner of the fourth cervical (C4) vertebra on a still frame of the videofluoroscopic image with the subject's head upright in a normal position revealed that older men had a significantly shorter C2 to C4 length (mean ± SE = 32.79 mm ± 1.11) than younger men (mean ± SE = 36.74 mm ± 1.08, $p = .02$). This difference of 4 mm in length of neck will be considered in the discussion of significant differences seen in extent of vertical movement of the hyoid and larynx.

Age Effects

Only one measure showed a significant interaction between age and bolus volume: width of cricopharyngeal opening. Older men had a smaller cricopharyngeal opening width on both volumes than younger men, but this difference was only significant at 10 ml ($p < .001$).

Pharyngeal delay was the only duration measure that was significantly different for the older and younger men, with the older men exhibiting a significantly longer pharyngeal delay (.06 s ± .07) than younger men (–.15 s ± .03, $p = .01$).

Older men had earlier onset of base of tongue movement, posterior pharyngeal wall movement, laryngeal closure, and bolus reaching the pyriform sinus in relation to first cricopharyngeal opening than younger men, but only posterior pharyngeal wall movement was statistically significant earlier than in older men ($p = .04$).

The extent of structural movement at first cricopharyngeal opening was less for older men than younger men on all measures, but only hyoid elevation was significantly less (19.33 mm ± 1.76 for younger men and 12.47 mm ± 1.54 for older men, $p = .01$), and this difference remained significant after accounting for the difference in neck length ($p = .04$). Younger and older men

Table 3. Mean (± SEM) swallow measures by age group. Statistics are based on 32 swallows, two 1 ml and two 10 ml, for each of the 8 younger men and 8 older men.

Swallow measure	Younger	Older	*p* value
Duration (s)			
Pharyngeal delay	–.15 (.03)	.06 (.07)	.01*
Base of tongue contact to pharyngeal wall	.31 (.05)	.40 (.03)	.14
Cricopharyngeal opening	.42 (.02)	.43 (.02)	.77
Laryngeal closure	.51 (.04)	.56 (.04)	.44
Onset (s) in relation to first cricopharyngeal opening			
Base of tongue movement (s)	–.15 (.03)	–.19 (.05)	.58
Posterior pharyngeal wall movement (s)	–.12 (.03)	–.23 (.04)	.04*
Laryngeal closure (s)	.02 (.02)	–.02 (.02)	.21
Bolus reaches pyriform sinuses (s)	.03 (.03)	–.03 (.01)	.12
Extent (mm) of structural movement in relation to first cricopharyngeal opening			
Laryngeal elevation (mm)	25.30 (2.89)	19.12 (1.88)	.09
Anterior laryngeal movement (mm)	4.23 (1.18)	2.82 (1.38)	.45
Hyoid elevation (mm)	19.33 (1.76)	12.47 (1.54)	.01*
Anterior hyoid movement (mm)	7.28 (1.08)	5.14 (1.36)	.24
Time (s) to maximum cricopharyngeal opening in relation to first cricopharyngeal opening	.14 (.01)	.13 (.01)	.49
Maximal extent of structural movement (mm)			
Base of tongue movement at inferior C2	9.80 (.94)	7.76 (.86)	.14
Posterior pharyngeal wall anteriorly at inferior C2	7.02 (.65)	5.83 (.57)	.19
Width of cricopharyngeal opening: 1 ml	6.44 (.66)	6.00 (.74)	.66
10 ml	11.89 (.46)	9.33 (.43)	<.001*
Posterior movement of epiglottic base	5.88 (.69)	6.48 (1.04)	.64
Anterior movement of arytenoid	3.81 (.80)	4.62 (.46)	.40
Laryngeal elevation	33.88 (3.03)	24.25 (1.58)	.01*
Anterior laryngeal movement	8.16 (2.24)	6.18 (.93)	.43
Hyoid elevation	25.04 (1.56)	14.58 (1.46)	<.001*
Anterior hyoid movement	14.62 (2.21)	8.47 (1.05)	.02*

*$p < 0.05$

did not differ in the time it took them to move from initial cricopharyngeal opening to maximum cricopharyngeal opening.

Except for the movement components of airway closure (posterior movement of the epiglottic base and anterior movement of the arytenoid cartilage), maximal extent of structural movement was less in the swallows of older men than those of younger men. This was significantly so for width of cricopharyngeal opening on 10-ml swallows (by 2.5 mm, $p < .001$), anterior hyoid movement (by 6.1 mm, $p = .02$), laryngeal elevation (by 9.6 mm, $p = .01$), and hyoid elevation (by 10.5 mm, $p < .001$). When data were reanalyzed with neck length as a covariate, the only change in significance of vertical movement was in elevation (older men, less by 7.0 mm), which became nonsignificant. Younger men still exhibited significantly greater vertical hyoid movement. The age differences (either unadjusted or adjusted for neck length) in these latter two vertical measures are greater than the difference in neck length between younger and older men (4.0 mm). Therefore, these differences are interpreted as a real age effect regardless of neck length.

Volume Effects

See Table 4. Only for maximal width of cricopharyngeal opening was there a significant interaction between age and volume; therefore, this measure was analyzed separately by age group in the volume analysis. Width of cricopharyngeal opening increased significantly ($p = < .001$) from 1 to 10 ml for both age groups but more so in the younger men (6.44 ± .66 to 11.89 ± .46 mm) than in the older men (6.00 ± .74 to 9.33 ± .43 mm).

Significant changes with volume increase were seen to be increased duration of cricopharyngeal opening, later onset of base of tongue movement, posterior pharyngeal wall movement and airway closure in relation

Table 4. Mean (± SEM) swallow measures by bolus size. Statistics are based on 32 swallows, two 1 ml and two 10 ml, for each of the 8 younger men and 8 older men.

Swallow measure	1 ml		10 ml		p value
Duration (s)					
Pharyngeal delay	–.02	(.07)	–.07	(.03)	.55
Base of tongue contact to pharyngeal wall	.40	(.04)	.32	(.04)	.07
Cricopharyngeal opening	.35	(.02)	.51	(.02)	<.001*
Laryngeal closure	.51	(.03)	.56	(.04)	.36
Onset (s) in relation to first cricopharyngeal opening					
Base of tongue movement (s)	–.28	(.04)	–.06	(.03)	<.001*
Posterior pharyngeal wall movement (s)	–.27	(.03)	–.08	(.03)	<.001*
Laryngeal closure (s)	–.03	(.01)	.02	(.026)	.01*
Bolus reaches pyriform sinuses (s)	.001	(.026)	.003	(.015)	.92
Extent (mm) of structural movement in relation to first cricopharyngeal opening					
Laryngeal elevation (mm)	23.49	(2.15)	20.94	(1.65)	.14*
Anterior laryngeal movement (mm)	6.79	(1.98)	7.54	(.84)	.69
Hyoid elevation (mm)	18.14	(1.40)	21.47	(1.14)	.02*
Anterior hyoid movement (mm)	11.22	(1.74)	11.87	(1.10)	.68
Time (s) to maximum cricopharyngeal opening in relation to first cricopharyngeal opening	.12	(.02)	.15	(.01)	.12
Maximal extent of structural movement (mm)					
Base of tongue movement at inferior C2	8.78	(1.01)	8.78	(.64)	.99
Posterior pharyngeal wall anteriorly at inferior C2	5.90	(.55)	6.95	(.55)	.13
Width of cricopharyngeal opening: Younger	6.44	(.66)	11.89	(.46)	<.001*
Older	6.00	(.74)	9.33	(.43)	<.001*
Posterior movement of epiglottic base	5.83	(.63)	6.53	(.83)	.36
Anterior movement of arytenoid	4.29	(.46)	4.15	(.63)	.82
Laryngeal elevation	27.69	(2.05)	30.43	(1.68)	.08
Anterior laryngeal movement	6.79	(1.98)	7.54	(.84)	.69
Hyoid elevation	18.14	(1.40)	21.47	(1.14)	.02*
Anterior hyoid movement	11.22	(1.74)	11.87	(1.10)	.68

*$p < 0.05$

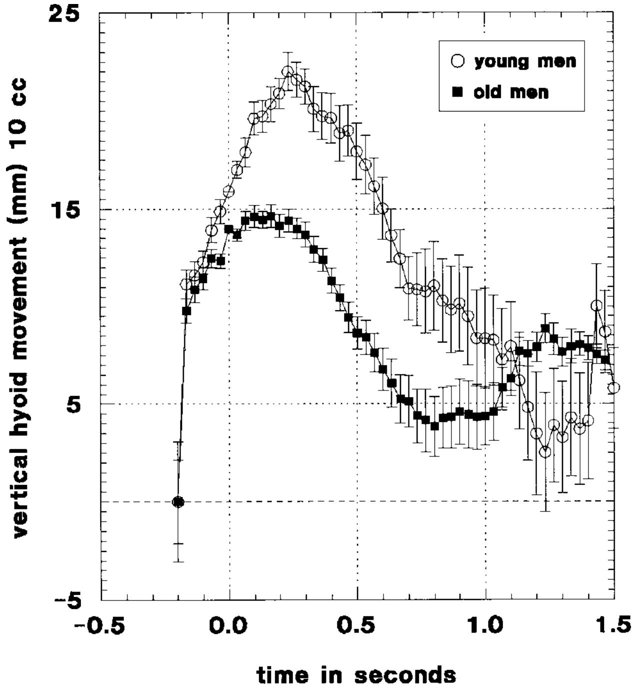
to first cricopharyngeal opening, greater extent of hyoid elevation at first cricopharyngeal opening, and greater maximal hyoid elevation.

Vertical position of the larynx at rest in mm from the anterior inferior corner of C4 was also measured to determine whether the larynx was significantly lower in the neck of the older men. Though older men had a lower laryngeal position (mean ± SE = 26.18 mm, 2.76 mm) than younger men (mean ± SE = 23.12 mm, 3.95 mm), the difference was not statistically significant ($p = .60$).

The pattern of hyoid motion was observed during each swallow of the younger and older men. An upward and then forward movement was most common for both groups of subjects, with 78% (25) of the younger men's swallows exhibiting this pattern and 61% (20) of the older men's swallows reflecting this pattern of hyoid movement. Frequency and use of this predominant pattern of hyoid movement was not different for the two age groups. A circular pattern occurred in 70% (15) of the remaining 19 swallows, whereas a relatively straight diagonal movement was seen in 30% (4) of the remaining swallows.

The concept of reduced reserve in the motor control of the elderly (reduced maximal movement of a structure while still accomplishing the desired motor task) was examined in this data set by developing movement-over-time graphs of the pharyngeal motions that were significantly different despite differences in the length of the neck in younger and older men (i.e., vertical and anterior motion of the hyoid). Figure 2 presents such a graph for vertical hyoid motion on 10 cc boluses for older and younger men. Time 0 on this graph represents first cricopharyngeal opening. This event was selected because it is a very stable event in swallowing and hyoid and laryngeal movement contribute significantly to opening of the upper esophageal sphincter (Cook et al.,

Figure 2. Plot of averaged vertical hyoid movement at 1/30th of a second intervals on 10-cc liquid swallows for the 8 younger men and 8 older men. Time 0 represents the first frame showing cricopharyngeal (upper esophageal) opening.

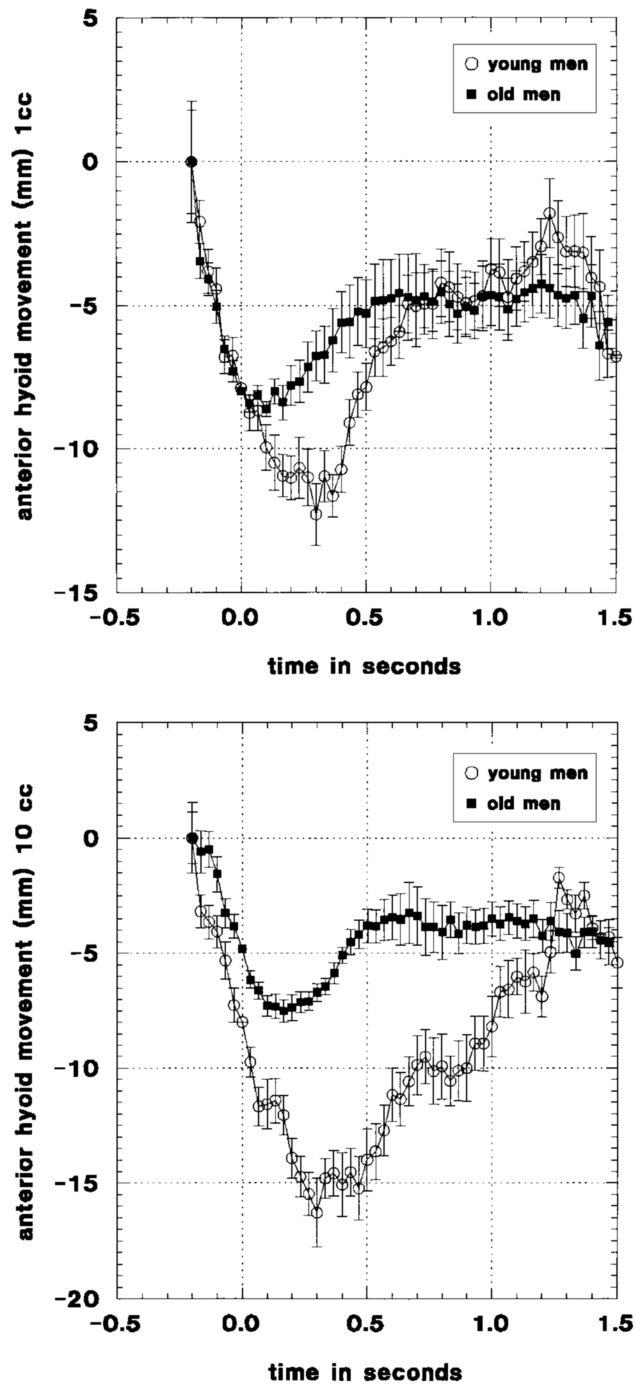


1989; Jacob, Kahrilas, Logemann, Shah, & Ha, 1989). As shown in Figure 2, the pattern and extent of vertical movement of the hyoid is virtually identical in the younger men and older men to the point of cricopharyngeal opening. Then the hyoid continues to move upward in the younger men, but remains relatively stable in the older men. The significant differences in the maximum hyoid and laryngeal elevation and anterior hyoid movement in the younger and older men reflect reduction in reserve in these movements in the older men. Figure 3 presents the anterior movement of the hyoid at 1- and 10-ml volumes for the younger and older men.

Discussion

These data on normal swallowing in younger and older (80+ years) men support and extend the results of a number of prior studies on the effects of aging on normal deglutition. The prolonged pharyngeal delay observed in the men 80 years and older in this study are in agreement with the same observation seen in men and women in the 60- to 79-year-old age group (Robbins et al., 1992). Interestingly, the magnitude of the delay was not increased in these men 80+ years old, possibly indicating that once the pharyngeal swallow is delayed with aging the delay does not continue to increase as normal aging continues.

Figure 3. Plots of mean anterior hyoid movement at 1/30th of a second intervals on the two 1-cc and two 10-cc liquid swallows of the 8 younger men and 8 older men. Time 0 represents the onset of cricopharyngeal (upper esophageal sphincter) opening. Because the subject is positioned in the radiographic field with the hyoid to the left of the origin of the measurement system (i.e., the anchor point at anterior-inferior corner of C4), increases in anterior movement are indicated by larger negative values on the graph as the structure moves further away from the anchor point.



Ekberg (1986) reported patterns of hyoid movement during normal swallow in 50 healthy individuals between the ages of 20 and 79. Eighty percent of these individuals exhibited what he called a "two step" pattern of hyoid movement (up and forward). The predominant pattern of hyoid movement seen in our study of healthy older and younger men showed this same predominant pattern of two-step, up and forward, hyoid movement. Volume changes were also compatible with earlier reports.

Results of this study in normal older and younger men reflect two important changes in the physiology of oropharyngeal swallowing that have been reported in the literature regarding neuromuscular effects on normal aging: reduced reserve and reduced flexibility. Differences in hyoid movement during swallow between the older and younger men reflect reduced reserve. Hyoid movement in the younger men continues beyond the extent needed to open the cricopharyngeal region (upper esophageal sphincter—UES). The difference between the extent of the movement needed to accomplish the desired functional result (UES opening) and the actual extent of movement used is reserve. By this definition, younger men had a great deal of reserve. In comparison, the older men had hyoid movement similar to younger men up to the point of initial UES opening. While hyoid movement continued after UES opening in younger men, hyoid movement essentially stopped at that point in the older men. These data indicate that the older men had no reserve in this neuromuscular activity.

In the younger men, a distinct and previously reported increase in duration and diameter of UES opening was seen as bolus volume increased (Jacob et al., 1989). These changes were less dramatic in the older men, indicating less flexibility in this mechanism as well. There is reason to believe that exercise programs can result in improvement in hyoid and laryngeal movement during swallow. Shaker et al. (1997) have reported significant improvement in these movements during swallow in normal older subjects (ages 62 to 91) after an exercise program involving head-lifting from a supine position. Literature supporting the positive physiologic and functional effects on skeletal muscle of both resistance and aerobic exercises regardless of age in healthy, community-living older individuals is rapidly increasing (Ades et al., 1996; Aniansson, Ljungberg, Rundgren, & Wetterqvist, 1984; Chandler & Hadley, 1996; Evans, 1995; Fiatarone & Evans, 1993; Fiatarone et al., 1990, 1994; Frontera, Meredith, O'Reilly, Knuttgen, & Evans, 1988; Grimby et al., 1992; Judge, Whipple, & Wolfson, 1994; Morey et al., 1991; Sidney & Shephard, 1978; Wolf, Kutner, Green, & McNeely, 1993).

Although there are 8 persons per age group in this study, there are 2 swallows per person at each bolus volume. This results in 32 swallows for each of the age groups or bolus volumes. Most of the analyses are based on comparison groups of 32 swallows. Statistical power depends on the correlation of swallows made on the same person. This study has 80% power to detect an effect size (mean difference/standard deviation) of 0.70 to 1.40 as the within-person correlation ranges from 0 to 1.

These results may help to explain several medical problems in the elderly, particularly why they contract pneumonia, the leading cause of death in individuals over 80, more easily and quickly than younger adults (LaCroix, Lipson, Miles, & White, 1989). We may hypothesize that if elderly men become weak from illness, their lack of reserve may cause them to lose range of motion in the hyoid and larynx needed to open the upper esophageal sphincter adequately, resulting in unsuspected dysphagia and aspiration, which could lead to pneumonia. Similar studies in a larger cohort of healthy older men and women need to be completed.

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