Published in final edited form as:

Clin Otolaryngol. 2011 February ; 36(1): 30–36. doi:10.1111/j.1749-4486.2010.02219.x.

The relationship between hyoid and laryngeal displacement and swallowing impairment

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Abstract

Objectives—Reduced range of hyoid and laryngeal movement is thought to contribute to aspiration risk and pharyngeal residues in dysphagia. Our aim was to determine the extent to which movements of the hyoid and larynx are correlated in the superior and anterior directions in swallowing, and whether movement range is predictive of penetration-aspiration or pharyngeal residue.

Design—Prospective, single-blind study of penetration-aspiration and pharyngeal residue with objective frame-by-frame measures of hyoid and laryngeal excursion from videofluoroscopy.

Setting—Tertiary hospital and rehabilitation teaching hospital.

Participants—28 participants referred for videofluoroscopy: 13 females, aged 57-77; 15 males aged 54-70. Individuals with known neurodegenerative diseases or prior surgery to the neck were excluded. Each swallowed three boluses of 40% w/v thin liquid barium suspension.

Outcomes—Two speech-language pathologists independently rated penetration-aspiration, vallecular and pyriform sinus residue. Cervical spine length, hyoid and laryngeal displacement were traced frame-by-frame. Predictive power was calculated.

Results—Cervical spine length was significantly greater in males. Hyoid displacement ranged from 34-63% of the C2-4 distance. Arytenoid displacement ranged from 18-66%, with significantly smaller anterior displacement in males. Positive hyoid-laryngeal movement correlations in both axes were the most common pattern observed. Participants with reduced displacement ranges (first quartile) and with abnormal correlation patterns were more likely to display penetration-aspiration. Those with reduced anterior hyoid displacement and abnormal correlation patterns had a greater risk of post-swallow pharyngeal residues.

Conclusions—It is difficult for clinicians to make on-line appraisals of the extent to which hyoid and laryngeal movement may be contributing to functional swallowing consequences during videofluoroscopy. This study suggests that it is most important for clinicians to discern whether reduced *anterior displacement* of these structures is contributing to a patient's swallowing impairment. Measures of structural displacement in thin liquid swallowing should be corrected for

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Conflicts of interest: None to declare

variations in participant height. Reductions in anterior hyoid and laryngeal movement below the first quartile boundaries are statistically associated with increased risk for penetration-aspiration and post-swallow residues.

A number of abnormalities in the pharyngeal phase of swallowing are attributed to reduced range of hyoid and laryngeal movement. Specifically, it is claimed that reduced vertical excursion of the hyo-laryngeal complex contributes to incomplete airway closure with an associated risk of aspiration¹. Reduced hyoid displacement in the anterior direction is thought to contribute to reduced opening of the upper esophageal sphincter resulting in pyriform sinus residues².

Recent studies in the literature have focused on the relationship between maximum hyoid excursion and various functional outcomes. These studies have typically reported hyoid displacement in millimeters, comparing hyoid position on a single frame of maximum displacement to a pre-swallow rest position, with the vertical axis of movement defined by a line running through the anterior inferior corners of the 2nd and 4th cervical vertebrae³⁻⁶. These studies show large standard deviations and do not consistently control for differences in participant height⁷. Studies disagree regarding the presence of gender differences^{3, 5}. The relationship between range of structural displacement and functional consequences remains unclear.

Although the hyoid and larynx are described to have similar movement trajectories, the extent to which their movement is correlated remains unclear. The literature to date lacks studies in which the entire movement trajectories of both the hyoid and larynx have been traced frame-by-frame, and in which superior and anterior movement distances have been analyzed as predictors of disordered swallowing, controlling for differences in participant height. Our aim, using a sample of adults referred for swallowing assessment, was to determine whether relationships exist between the occurrence of a) penetration-aspiration, b) post-swallow pharyngeal residues, and: c) reductions in hyoid and/or laryngeal movement range; and d) abnormal patterns of hyoid-laryngeal movement correlation.

Materials and Methods

Ethical considerations

The research ethics boards of the Toronto Rehabilitation Institute and the Toronto East General Hospital approved this study. All participants gave written informed consent.

Participants

Twenty-eight adults participated in the study. All were referred for videofluoroscopic swallowing study to investigate swallowing complaints. The exclusion criteria were a history of head and neck cancer, tracheostomy, neurodegenerative disease, gastrointestinal disorders, or head and neck surgery other than routine tonsillectomy or adenoidectomy. The sample included 13 females (mean age 67, 95% confidence interval: 57-77) and 15 males (mean age 62, 95% confidence interval: 54-70).

Instrumentation

Lateral videofluoroscopy was captured digitally into a Labview computer program at 30 frames per second. The image boundaries were as follows: a) the lips anteriorly; b) the nasal passages superiorly; c) the posterior margin of the cervical vertebrae posteriorly; and d) the cervical esophagus inferiorly. A scalar reference of known dimensions (paper clip) was attached to a head-wire worn by each participant, and visible in the image field.

Procedure

A series of three 5-cc thin liquid swallows was captured at the beginning of each participant's videofluoroscopy examination. A command-swallow paradigm was used (i.e., participants were instructed to sip and wait for a verbal cue from the clinician before swallowing).

Stimuli

A 40% weight/volume thin liquid barium suspension was prepared using Polibar liquid barium suspension and water.

Data processing

Individual swallow video-clips were spliced from the master video recording using Visual Studio 2008 software. The onset of each clip was defined as 1 second (30 frames) before arrival of the bolus head at the shadow of the mandibular ramus. The termination of each clip was defined as 1 second (30 frames) after the hyoid returned to a rest position following bolus passage through the upper esophageal sphincter. This process resulted in a total data set of 84 single-swallow video-clips. In 15 of the clips, poor image quality or obstructed views of target structures by the shoulder shadow meant that frame-by-frame tracking was not possible. The final data set for analysis comprised 69 single-swallow video-clips.

Movement tracing

The video-clips were individually opened in Visual Studio for structural movement tracing. The following structures were traced in each video frame (see Figure S1): a) anterior inferior corner of the C4 vertebra (origin); b) anterior inferior corner of the C2 vertebra; c) anterior inferior corner of the hyoid; d) anterior superior corner of the arytenoid cartilages; e) end points of the scalar reference. A coordinate system was defined with the vertical axis running from point a) through point b) and the horizontal axis running perpendicular to this line through the origin (point a). The magnitude of the C2-4 distance, in millimeters, was calculated using the paper-clip scalar reference. An anatomical scaling factor was then defined as the vertical distance between points a) and b) (i.e., the C2-4 distance) and used for all displacement measures. The Visual Studio program continuously calculated the position of the hyoid and arytenoid cartilages relative to the origin and the magnitude of the anatomical scaling factor. When the marking was complete, all scaled positional data were exported to a text file. Scaled superior and anterior movement distances (i.e., % C2-4 distance) were computed as the difference between the maximum and minimum values in the positional data series for each video-clip. Pearson-product moment correlations were calculated between the hyoid and arytenoid positional data. For the analyses of predictive utility, displacement measures were collapsed into binary scores as follows: a) reduced (i.e., falling at or below the 1st quartile for axis-specific structural movement); b) not-reduced (i.e., above the 1st quartile). Correlation patterns were also collapsed into binary classes as follows: a) positive correlations > 0.5 for both superior and anterior displacement; b) other correlation pattern observed.

Parameter rating

The individual swallow video-clips were arranged in a random order and rated independently by 2 experienced speech-language pathologists. Raters were blinded to participant information; they knew the purpose of the study and the bolus size and consistency. The rating process included the 8-point Penetration-Aspiration scale⁸ and the Eisenhuber 4-point ordinal rating scales of post-swallow vallecular and pyriform sinus residue⁹. These ratings were reduced to binary scores (penetration-aspiration scale scores of 1 vs. 2 and higher; residue scores of 0 vs. 1 and higher) prior to further analysis¹⁰. Inter-rater

bolus-by-bolus agreement on the final binary scores was moderate ($\kappa = 0.46$) for penetration-aspiration and strong ($\kappa = 0.6$) for residues, respectively¹¹.

Data analysis

Inter-rater agreement was calculated using Cohen's Kappas (κ) for categorical data¹¹. A univariate analysis of variance was used to evaluate gender differences in participant height, represented by the C2-4 distance. Mixed-model analyses of variance were used to evaluate differences in anatomically-scaled displacement measures according to gender, and binary penetration-aspiration and residue dispositions, with a repeated measures factor of swallow. Binary classification scores for anatomically-scaled displacement range and correlation pattern were cross-tabulated with binary penetration-aspiration and residue dispositions. Chi-square analyses, sensitivity, specificity and likelihood ratios were calculated to evaluate predictive relationships. The literature suggests that good predictive utility requires high scores (i.e., 0.7) for sensitivity and specificity and a likelihood ratio greater than 1¹². All statistical analyses were completed using SPSS 18.0.

Results

Descriptive statistics for anatomical and displacement measures are shown in Table S1 for the overall sample, between genders (where gender differences were observed) and as a function of swallowing outcome (presence of penetration-aspiration and of residue). Participant height, represented by the length of the C2-4 distance (in millimeters), was significantly larger in male participants, $F(1, 27) = 10.50$, $p = 0.003$. When adjusted for height, upward displacement of the hyoid and larynx were similar in magnitude in both genders, with 95% confidence intervals ranging from 0.51-0.66 of the C2-4 distance. Anterior movement of the hyoid ranged from 33-42% of the C2-4 distance. Anterior movement of the arytenoid cartilages was significantly larger in female participants than males, $F(1, 28.15) = 4.654$, $p = 0.04$. Positive correlations of 0.5 or higher were observed between the hyoid and arytenoids in both axes in the majority (59%) of the video-clips rated for this study. There were no significant differences in anatomically-scaled displacement measures between those swallows exhibiting penetration-aspiration and no penetration-aspiration, or between those with and without post-swallow pharyngeal residue.

Assessment of factors affecting swallowing impairment scores

A significantly higher occurrence of penetration-aspiration was found in swallows where anterior movement of the hyoid fell below the first quartile boundary, $\chi^2_{(df, 69)} = 6.15$, $p = 0.013$, and arytenoids, $\chi^2_{(df, 69)} = 4.68$, $p = 0.03$. Reduced anterior arytenoid displacement (i.e., below the first quartile boundary) was also significantly associated with post-swallow pharyngeal residues, $\chi^2_{(df, 69)} = 3.923$, $p = 0.048$. Table S2 summarizes the predictive utility of the binary displacement and hyoid-laryngeal correlation pattern measures for penetration-aspiration and pharyngeal residues.

Discussion

Synopsis of key findings

These data confirm the importance of measuring hyoid and laryngeal displacement in units that are referenced to participant height. Given the significant differences in the length of the C2-4 intervertebral distance noted in these participants, it is not appropriate to compare structural displacement to references expressed in millimeters.

These data also suggest that anterior displacement of both the hyoid and larynx plays an important role in airway protection and bolus clearance in swallowing, and that these

functions are more commonly impaired when displacement falls below the first quartile boundaries. This is consistent with the physiological literature suggesting biomechanical advantages for upper esophageal sphincter opening with anterior displacement of these structures^{1, 2, 13}. Our finding that anterior structural movement is important for airway protection contrasts with previous suggestions that superior hyolaryngeal movement makes a primary contribution to this biomechanical phenomenon¹. However, it is important to note that not all the swallows exhibiting reduced displacement of the hyoid and arytenoids were pathological in functional terms (i.e., displaying penetration-aspiration and/or residue).

Axis-specific movements of the hyoid were positively correlated with those of the larynx in the majority of cases. However, an absence of positive movement correlation > 0.5 was not indicative of penetration-aspiration or pharyngeal residues.

Strengths of the study

To our knowledge, this is the first study of hyoid and laryngeal displacement in swallowing in which movements of both structures have been scaled according to cervical spine length. We identified differences in millimeter measures of the C2-4 vertebral distance in the magnitude of 8 mm, on average. By correcting for variations in participant height, gender differences along with the substantial variability present in previous studies of hyoid displacement are minimized. Additionally, this study did not adopt the practice from other studies of determining displacement based on a single frame of maximum excursion compared to a rest position. Rather, we sampled structural position in all video frames, beginning 1 second prior to swallow onset and continuing to 1 second after swallow conclusion, and derived axis-specific measures of displacement from these data. The frame of maximum superior excursion did not necessarily correspond to the frame of maximum anterior excursion, nor did the frame of maximum axis-specific hyoid excursion necessarily correspond to the frame of maximum axis-specific arytenoid excursion.

Methodological issues

One limitation of this study is the fact that we studied a referred sample. All participants were referred for videofluoroscopic swallowing assessment on the basis of clinical signs or symptoms of swallowing difficulty. Thus, it could be argued that none of these participants had truly normal swallowing. Nonetheless, the majority of swallows analyzed for this study were free from penetration-aspiration (70%) or post-swallow pharyngeal residues (74%), providing an adequate basis upon which to judge the relationship between structural movement and swallowing impairments in this referred sample. Furthermore, we applied strict exclusion criteria to avoid participants in whom prior surgery to the head and neck or a known neurodegenerative diagnosis might provide a reason to expect that the correlation between hyoid and laryngeal movement might be altered. In the sample studied, there was no a priori reason to expect that the etiology of the swallowing difficulties under investigation would specifically affect the suprahyoid and laryngeal muscles in a way that might alter this biomechanical relationship.

Clinical applicability of the study

It is difficult for clinicians to make on-line appraisals of the extent to which hyoid and laryngeal movement may be contributing to functional swallowing consequences during videofluoroscopy. In particular, it is difficult to correct for cervical spine angle (versus an upright axis on the image) during on-line analysis, in order to determine the adequacy of superior movement and of anterior movement perpendicular to that plane. Furthermore, it is difficult to judge the magnitude of structural movement without quantitative measurement of displacement distance from still frame images. This study suggests that it is most important for clinicians to discern whether reduced *anterior displacement* of these structures is

contributing to a patient's swallowing impairment. Table S1 provides lower boundaries for 95% confidence intervals for all displacement measures in this sample, as well as the first quartile boundaries that were used in our predictive utility analysis. For anatomically-scaled anterior structural displacement, the first quartile boundaries identified in this study were 0.27 and 0.19 of the C2-4 distance for the hyoid and arytenoids, respectively. We suggest that these numbers may be used by clinicians as references for determining when anterior hyoid and laryngeal movement are reduced. When this is identified as a possible contributing factor to penetration or aspiration, interventions that are intended to increase anterior hyoid and laryngeal excursion may be of benefit in reducing aspiration in these patients. Specifically, the Mendelsohn maneuver¹³⁻¹⁵ and the Shaker exercise¹⁶ are interventions that should be explored for such patients.

Conclusion

We have shown that measures of structural displacement in swallowing should be corrected for variations in participant height, using a normalization procedure based on the length of the cervical spine. Substantial reductions in anterior hyoid and laryngeal movement (i.e., below the first quartile boundaries) during thin liquid swallowing are statistically associated with increased risk for penetration-aspiration and post-swallow residues.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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