Intra- and Inter-rater Reliability for Analysis of Hyoid Displacement Measured with Sonography

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ABSTRACT: *Purpose.* Anterior hyoid displacement is essential for efficient swallowing and is usually investigated with videofluoroscopy. Ultrasound offers a less expensive and noninvasive method of investigation. The present study investigated the viability of a novel method of quantifying hyoid displacement from sonograms using an anatomic reference point, through an evaluation of inter- and intra-rater reliability.

Methods. Three raters reviewed the sonographic video sweeps of five discrete swallows from each of five participants for inter-rater reliability. The primary investigator measured each swallow on two occasions for intra-rater reliability. Electronic calipers were used to measure distances from a ''rest'' frame prior to the swallow of interest and a ''maximal displacement'' frame, at which the hyoid bone was at maximal anterior displacement during each swallow.

Results. Single-measure intraclass correlation coefficient was high for inter-rater agreement at 0.86 for rest measures and 0.86 for maximal displacement. Intra-rater reliability was even higher at 0.95 for rest and 0.98 for maximal displacement.

Conclusions. These preliminary results suggest that by using a novel analysis approach involving an anatomic reference point, raters can achieve high agreement on measurement of position of hyoid at maximal displacement relative to rest. *J Clin Ultrasound* **40**:74–78, 2012; Published online in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/jcu.20874

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Anterior hyoid displacement is essential for effective swallowing. Assessing the magnitude of hyoid displacement is therefore of interest in both clinical and research environments. This movement of the hyoid is a component of hyolaryngeal excursion, a biomechanical event that lifts the larynx and hyoid bone in both a superior and an anterior direction.[1] This displacement is caused, in large part, by contraction of the submental (floor of mouth) muscles during swallowing, specifically the paired mylohyoid, anterior belly of digastric, and geniohyoid muscles. The results of hyolaryngeal excursion are twofold: the epiglottis deflects to assist airway protection[2] and the upper esophageal sphincter is pulled open to allow bolus transfer from the pharynx to the esophagus.[1] Swallowing impairment (also known as dysphagia) is often characterized by reduced hyoid displacement during swallowing. Reduced hyoid movement has been associated with increased risk of airway invasion and pharyngeal residue,[3] highlighting the need for accurate assessment of hyolaryngeal excursion in dysphagia management.

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Hyoid displacement is commonly investigated with videofluoroscopy (VFS).[4–6] VFS provides visualization of temporal and spatial aspects of displacement; however, quantification of spatial aspects requires an involved process of calibration and data transformation.[4,6,7] Additionally, the use of VFS to obtain normative data of hyoid displacement in healthy participants is difficult to justify due to cumulative ionizing radiation exposure.

Ultrasound offers a relatively inexpensive and noninvasive method of investigation but has received little attention in the literature, despite its documented use for acquiring temporal measures of oropharyngeal movements during swallowing over two decades ago.[8] Real-time ultrasound provides a simple method by which to quantify temporal measures of hyoid displacement. However, studies utilizing ultrasound to investigate spatial aspects of hyolaryngeal excursion have historically required the same complex calibration and transformation processes as VFS.[9,10] A study by Scarborough and colleagues[11] quantified hyoid trajectory in children without such data transformation or calibration. Unlike previous studies, they did not employ stringent methods of head and transducer position control. Maintaining the position of the transducer relative to the head is crucial to control for movement artifact and to ensure accurate measures of true hyoid displacement are obtained.[12] As the method of calculating displacement in Scarborough et al's study cannot distinguish subtle transducer movement from genuine hyoid displacement, improved methods are required to control for the possibility of movement artifact. By restricting head and transducer placement, high reliability of hyoid measurement can be achieved.[9,10] However, the use of stabilization devices makes implementation of ultrasound in the clinical setting less straightforward, as units are often cumbersome and not portable (see ref. [13] for review). Although simpler methods of head stabilization have been reported in studies of hyoid displacement,[10,11] head movement can occur in many planes, and the efficacy of these simplistic methods in reducing movement artifact is yet to be confirmed through repeated measures. The present study utilized ultrasound to quantify hyoid movement according to an anatomic reference point, therefore eliminating the need for data calibration and transformation, and providing a constant reference by which to monitor transducer movement. This preliminary study was conducted to assess the viability of this novel method through an evaluation of inter- and intra-rater reliability.

MATERIALS AND METHODS

Five healthy volunteers (two men and three women, aged between 20 and 50 years) were recruited for one session. Participants had no history of surgery or disease affecting the head and neck musculature. Ethical approval was obtained from the local institutional review board. Informed consent was obtained prior to commencement of data collection.

A IU22 scanner (Philips Ultrasound, Bothell, WA) was used with a 5–1 MHz curved-array transducer. The C 5–1 MHz transducer provided a balance between adequate resolution and sufficient field of view to incorporate both the hyoid bone and the mental spine of the mandible in a single sonogram. Midsagittal grayscale sonograms were obtained as individual video segments of 8 seconds to record each swallow. Sonograms included the shadows cast by the hyoid bone and mental spine of the mandible. A generous amount of gel was used for acoustic coupling and minimal pressure was placed on the floor of the mouth surface throughout sonogram acquisition so as not to distort swallowing movements. Sonograms were acquired and then processed offline.

The primary investigator acquired all sonograms. These were taken with the participant sitting upright. Participants were instructed to sit comfortably and relax their head in a neutral position. The transducer was placed in a sagittal plane, at approximately midline between the lateral edges of the mandible, perpendicular to the floor of mouth muscle group. Participants were instructed to maintain a relaxed position and not flex the neck to accommodate placement of the transducer. Additionally, they were asked to maintain their tongue in a relaxed position when they were not swallowing. Depth settings were tailored to accommodate individual anatomy, and gain settings were adjusted to allow optimal visualization of the shadows cast the hyoid and mental spine of the mandible. Once the researcher initiated recording of the video loop, the participant was prompted to swallow their saliva as they usually would. Five swallows were recorded from each of the five participants. There was a time lapse of no less than 30 seconds between swallows so that participants could accrue saliva to avoid excess tongue movement prior to the subsequent swallow. The primary and two coinvestigators completed data analysis to derive inter-rater reliability, with the primary investigator analyzing the data a second time for intra-rater reliability.

The five swallows of each participant were measured by the primary investigator and then

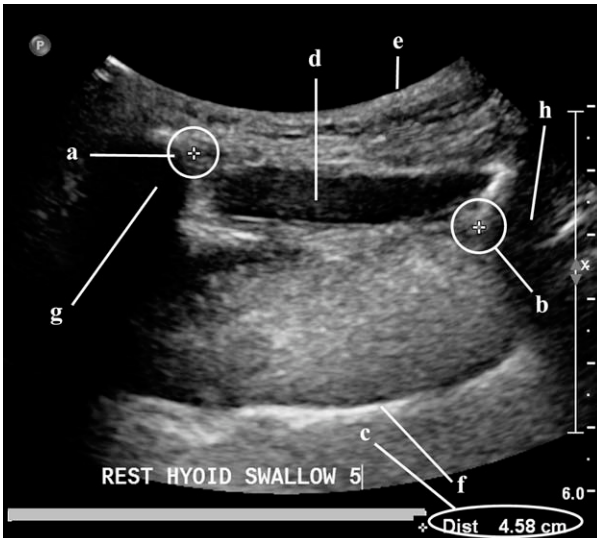

FIGURE 1. Sonogram of the hyoid/spine of mandible distance at rest. Electronic calipers mark the points at which the distance between mental spine of mandible shadow (**A**) and the intersection of the hyoid shadow with the geniohyoid muscle (**B**) is calculated (distance displayed at bottom right of sonogram (**C**)). Geniohyoid (**D**), skin surface (**E**), tongue surface (**F**), shadow cast by the mental spine of mandible (**G**), shadow cast by the hyoid bone (**H**).

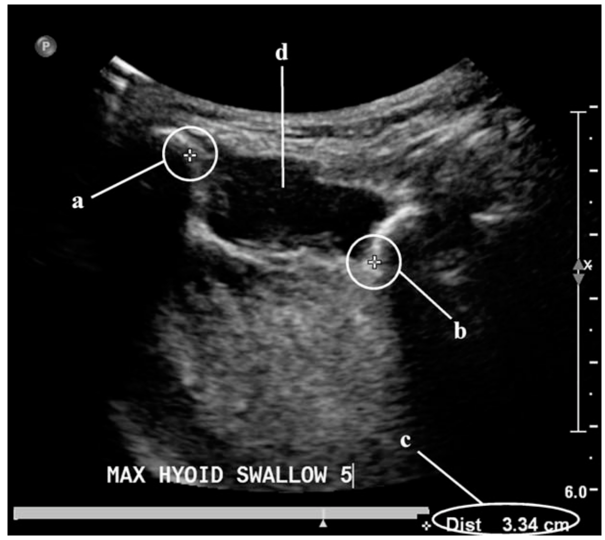

FIGURE 2. Sonogram of the hyoid/spine of mandible distance at the point of maximal displacement. Note the thickening of the geniohyoid muscle (**D**) due to contraction during maximal displacement. Although the caliper mark at the mental spine of the mandible (**A**) remains the same as the rest position, the caliper denoting the hyoid shadow (**B**) has shifted anteriorly toward the mental spine of the mandible. The calculated distance is shorter than that for rest position (**C**).

independently by the other two investigators, followed by the primary investigator again. Each investigator was blinded to the measurements made by the other two investigators. As all swallow video segments were recorded by the primary investigator, reliability reflects measurement of data only and not sonogram acquisition. All measures were done in one session on the same day. Prior to data acquisition, consensus was reached for definition of placement of the reference and hyoid displacement calipers as follows: the reference caliper was defined as the point at which the shadow cast by the spine of the mandible intersected with the brightly echogenic cortical surface of the mandibular bone (Figure 1A and Figure 2A); the hyoid displacement caliper was defined as the point at which the shadow cast by the hyoid intersected with the geniohyoid muscle (Figure 1B and Figure 2B).

Each rater identified a "rest" frame prior to any oral movement related to the swallow of interest and a "maximal displacement" frame, at which the hyoid bone was at maximal anterior displacement during each swallow. Electronic calipers were used to measure the distance between the reference point and the hyoid point for each rest and maximal displacement frame.

Quantification of hyoid displacement, or the change from resting hyoid distance to maximal displacement distance, was calculated as a percentage of the distance traveled from rest (max distance – rest distance/rest distance $\times$ 100), and also as absolute value of distance traveled. Both were used for analysis to elucidate the more reliable method.

Statistical analysis

Statistical analysis was performed using Predictive Analytics SoftWare (PASW, SPSS Release 18.0). Inter- and intra-rater reliability were analyzed using the intraclass correlation coefficient (ICC) using an absolute agreement definition. As the focus was on level of agreement between raters rather than between participants, measurements from each rater, of each of the five swallows from each of the five participants, were included in the analysis. Therefore 25 ratings were compared for absolute agreement for each measure (rest, maximal displacement, percentage change, and absolute change). Intra-rater reliability was calculated from measures made by the primary investigator only. For this, the primary investigator measured all 25 swallows from the five participants on two separate occasions. Inter-rater reliability was calculated from the measures obtained from the three raters. The following ICC analyses were completed for both inter-rater and intra-rater reliability assessment:

1. Distance between hyoid and mandible at rest
2. Distance between hyoid and mandible at maximal displacement

TABLE 1
Single-Measure Intraclass Correlation Coefficients (ICCs) for Interrater Reliability

		ICC	95% CI	*p* Value
Distance between hyoid and mandible	At rest	0.86	0.76–0.93	<0.001
	Maximal displacement	0.86	0.69–0.94	<0.001
Change in hyoid displacement	% Change	0.70	0.45–0.85	<0.001
	Absolute change	0.64	0.40–0.81	<0.001

TABLE 2
Single-Measure Intraclass Correlation Coefficients (ICCs) for Intrarater Reliability

		ICC	95% CI	*p* Value
Distance between hyoid and mandible	At rest	0.95	0.89–0.98	<0.001
	Maximal displacement	0.98	0.96–0.99	<0.001
Change in hyoid displacement	% Change	0.93	0.85–0.97	<0.001
	Absolute change	0.90	0.80–0.96	<0.001

3. Percent change of hyoid position from rest to maximal displacement
4. Absolute change of hyoid position from rest to maximal displacement

RESULTS

Single-measure ICCs for inter-rater reliability are shown in Table 1. ICCs for intra-rater reliability are shown in Table 2. The range of the distance between the hyoid and mandible calipers was 4.6–5.9 cm at rest and 3.1–3.9 cm at maximal displacement. ICCs were high for inter-rater agreement at 0.86 for measures of resting distance and 0.86 for measures of maximal displacement. Intra-rater reliability was even higher at 0.95 for measures of resting distance and 0.98 for maximal displacement measures.

The range for the percentage change from rest to maximal displacement was 17–44%. The range for the absolute change of hyoid position was 0.8–2.6 cm. Regarding the reliability of quantification of hyoid movement, the inter-rater ICC for percentage change of hyoid position was greater than that for absolute change of hyoid position at 0.70 and 0.64, respectively. This was also the case for intra-rater ICCs at 0.93 and 0.90, respectively.

DISCUSSION

This preliminary study investigated the viability of a novel method of data analysis using ultrasound to quantify hyoid movement. This method utilized an anatomic reference point to eliminate the need for complex data transformation and calibration and to provide a constant reference by which transducer movement can be monitored. These data suggest that raters can achieve high agreement regarding measures of maximal hyoid displacement during swallowing when reviewing the same ultrasound swallowing sweeps. Although the measurements at rest and maximal displacement taken by each rater were highly correlated, there was a small reduction in agreement of percentage change and agreement of absolute change from rest to maximal displacement. This suggests that distances were measured by raters in a similar fashion; that is, larger distances were measured as such by each rater but that the actual values of the measures differed slightly from rater to rater. The fact that percentage change was more highly correlated than absolute change suggests that by normalizing values to the reference point, some of the variance in measurement is reduced. As this preliminary study presents data using a small number of samples, further validation of this novel method is required.

Although inter-rater reliability of measures of change were lower than the distance measurements at rest and maximal displacement, intra-rater measures of change remained high. This suggests that definition of caliper placement may vary slightly from rater to rater but, within a rater, definition of caliper placement remains more consistent.

Although the method of analysis evaluated in this study was measured with a high degree of reliability, further investigation is needed to assess the confounding intra-rater and intra-participant variability in data acquisition. Unlike some previous investigations of hyoid movement that have utilized ultrasound,[9,10] this study did not stabilize participants' heads or the transducer during the acquisition of swallowing sweeps. Instead, the present study employed a reference point (mental spine of mandible) in an attempt to eliminate the effect of transducer movement on displacement values and therefore remove the need for cumbersome and expensive stabilization devices. However, because each rater analyzed the sonograms taken by a single rater and did not acquire the video sweep independently, it would be desirable for the reliability of the entire process to be determined for future applications in both research and clinical settings. It is possible that variation of participant positioning would reveal the need for head and transducer stabilization. This may be especially pertinent for data acquired over different sessions, when maintenance of positioning cannot be ensured.

The use of ultrasound to document hyoid displacement in the clinical setting warrants further discussion. Whether hyoid displacement is sufficient for effective swallowing is determined by observation of the ensuing effects, particularly epiglottic deflection and opening of the upper esophageal sphincter. However, as ultrasound does not allow visualization of these biomechanical events, it is necessary to establish whether this method is useful for evaluation of disordered swallowing function in the absence of normative data acquired during unimpaired swallowing. It may be that individual variation in hyoid displacement makes documenting norms an ineffectual undertaking, but further assessment of reliability of measures taken would assist in resolving this concern.

Alternatively, if ultrasound is shown to be sensitive to changes in hyoid displacement as a result of swallowing rehabilitation techniques, intra-participant comparisons may prove clinically useful. Ultrasound may also provide a useful adjunct to videofluoroscopy in allowing correlation of ultrasound measures with biomechanical observations on videofluoroscopy, and changes in swallowing function. More frequent assessment of hyoid displacement can be carried out in between videofluoroscopic evaluations of swallowing using ultrasound.

In summary, our study appears to provide a useful approach to the measurement of hyoid displacement during swallowing, eliminating the need for complex data calibration and transformation. Using percentage change of hyoid displacement from resting position may offer a more reliable measure than absolute change. Further evaluation of the reliability of the entire process of data acquisition without stabilization devices should be completed before ultrasound can be incorporated into clinical assessment of swallowing disorders.

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