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An Ultrasound Examination of Tongue Movement during Swallowing

Maureen Stone[1], and Thomas H. Shawker[2]

Departments of [1] Rehabilitation Medicine and [2] Diagnostic Radiology, National Institutes of Health, Bethesda, Maryland, USA

Abstract. Six female adults were studied during the production of four single swallows each, using real-time ultrasound. A pellet was affixed to the tongue at the junction between the (calculated) anterior third and posterior two-thirds of the tongue surface. Direction, rate, and extent of pellet movement were measured and used to create stages of tongue blade movement during swallowing. Pellet movement was then compared to the three stages of hyoid movement (ascent, steady, descent). Anterior-posterior and superior-inferior components of pellet movement were examined and discussed.

Key words: Tongue, ultrasound, swallowing, pellet

Studies of swallowing have traditionally been performed using radiographic and fluoroscopic techniques (Ekberg et al. 1982; Logemann 1983; Yotsuya et al. 1981). Recently, ultrasound imaging has been applied to studies of the tongue (c.f. Shawker et al. 1984) and the oral stage of swallowing (Shawker et al. 1983; Sonies et al. 1984). The use of ultrasound to measure the oral stage of swallowing has several advantages over x-ray. First, there is no radiation effect. Second, midline submental transducer placement prevents obscuring of the tongue by the teeth and hard structures of the mouth. Finally, the tomographic image depicts deformation of the actual tongue surface, rather than primarily visualizing the bolus as occurs with x-ray. Measurements of tongue movement, when made from either radiographic or ultrasound images, can be of surface displacement or anterior-posterior movement of a single point on the tongue's surface. To make measurements of the latter type, pellets have traditionally been glued to the tongue and tracked using conventional x-ray techniques, x-ray microbeam (Fujimura 1981; Kiritani et al. 1975), and ultrasound (Shawker et al. 1985).

Pellet or point source tracking in humans has been concerned exclusively with speech maneuvers, however not with swallowing. Some animal work (Franks et al. 1984, 1985) has examined single-point movement of the tongue during swallowing. Pellets were surgically implanted in the tongue of various animals and tracked by cineradiography during eating maneuvers. This technique, however, is not feasible for use with humans.

The present study seeks to apply pellet tracking to swallowing research. This application promises to be most useful as there is little information at present on the nature of the tongue's movement during swallowing.

Observations of real-time ultrasound images clearly demonstrate the tongue's wave-like movement during swallowing (Shawker et al. 1983). By tracking a pellet affixed to the tongue blade, one can document the movement at a single point over time, revealing the nature of the waveform. Examination of the wave pattern of the tongue blade as it acts on and reacts to the bolus will supply baseline data against which to compare abnormal swallowing gestures.

When defining waveforms, it is common to talk of longitudinal and transverse movement. Transverse wave movement consists of vibration in which the particle oscillation of the medium is perpendicular to the direction of the wave. For example, an ocean wave is a transverse wave. As it passes by, it lifts and returns an object to roughly the same location; that is, displacement is at right

Address reprint requests to: Maureen Stone, Ph.D., Department of Rehabilitation Medicine, National Institutes of Health, Bldg. 10 Rm 5D37, Bethesda, MD 20892, USA

angles. In longitudinal wave movements, on the other hand, particle oscillation is in the same or parallel direction as the wave's propagation. This is true of a sound wave in which the air molecules through which the wave passes compress and rarefy in the same direction the wave is traveling. Clearly the tongue surface moves down and up (transverse movement) as the bolus passes over it moving from front to back. But is there anterior-posterior (longitudinal) movement as well? This can only be determined by tracking a pellet. The study presented in this paper examines movement of the tongue blade during swallowing by tracking the movement of a superficially affixed pellet using ultrasound imaging.

Methods

Subjects

Six normal adult females between the ages of 20 and 40 served as subjects. Tongue length for each was calculated in the following way: (1) Under direct inspection, a pellet was affixed 4.5 cm back on the protruded tongue. (2) Using ultrasound imaging, the surface distance from the pellet to the hyoid was measured while the tongue was at rest. (3) The posterior tongue length was added to the 4.5 cm anterior length to determine total tongue surface length.

Once tongue surface length was established, the first pellet was removed. Under direct inspection and measuring from the tongue tip, a second pellet was affixed at the junction between the calculated anterior third and the posterior two-thirds of the tongue surface. In the six subjects, this junction occurred between 3.9 and 4.5 cm back from the tip. The second pellet was used during actual data collection.

Pellet and Ultrasound Instrumentation

A 5 mm stainless steel sphere was affixed to the tongue using dental impression material (Impregum, Espe Co, W. Germany). The pellet was dipped in the impression material and placed on the tongue. The subject kept the tongue at rest for 3 min while the material set. Once set, the pellet remained immobile and firmly fixed on the tongue surface until the end of the recording session at which time it was removed manually. The pellet generated reverberation echoes with a periodicity spaced at 4.5 to 5.0 mm. Lateral width of the reverberation echos approximated 5.00 mm (Shawker et al., 1985).

Ultrasound images were made in real time using an Advanced Technology Laboratories, Inc. (Bellevue, WA) ultrasound unit. A mechnical sector scanner consisting of a rotating head with three 3-MHz transducers spaced at 120° around a central axis was employed in this study. Focal depth used was 9 cm, producing a frame rate of 37 frames per second. The focal point was 5 cm (approximately the depth of the tongue surface), and the focal zone was 3–8 cm. At the focal point, axial resolution was 1 mm, and lateral resolution was 1.9 mm.

Procedures

Each subject swallowed ten or more individual 20-cc boluses of water while the tongue was scanned using ultrasound. The ultrasound transducer was placed submentally and directed vertically. The tongue was scanned in the midsagittal plane and videotaped in real time. Digitally displayed timing information (timed to hundredths of a second) was inserted on the videotape, marking each frame with a separate time and facilitating duration measurements. Pellet movement was tracked frame by frame from the videotape during the course of the swallow using a Microsonics Inc. (Indianapolis, IN) microprocessor designed for use with ultrasound and in IBM-PC computer (International Business Machine Corp.). A program in the Microsonics provided xy coordinate numbers for every pixel on the video image. The pixel at which the pellet was located on each frame was stored as an xy coordinate in the IBM-PC. The scanned data then were converted to metric numbers using a scaling factor based on the ultrasound depth setting used when collecting the data.

Because no immovable hard structures from the oral cavity were visible in the image, pellet position relative to other articulators could not be determined. Therefore, measures of pellet movement were made relative to the preswallow "hold" position. The subject was instructed to hold the bolus in the front of the mouth until directed to swallow. The frame before pellet movement began was used as the reference position for subsequent pellet measurements.

Data Analysis

Four swallows were chosen from each subjects' data for further analysis. Two criteria were used in determining the optimal swallows. First, the pellet, tongue, and hyoid shadow had to be clearly visible throughout the entire swallow, and second, the tongue had to release its palatal contact in a timely fashion after the swallow, as discussed below. The frame before an abrupt change in pellet direction was considered to be the end of a stage. The duration of each stage of tongue movement was measured by two judges. Only swallows in which there was 100% agreement on stage duration were included.

Means and standard deviations for each subject were calculated for the following variables:

1. Distance moved by the pellet in each stage (cm)
2. Duration of each tongue stage (sec)
3. Distance (cm) moved by the pellet in the transverse and longitudinal plane for each stage
4. Duration (sec) of hyoid stages (see below)
5. Total swallow duration (sec) (described below)

The terms "longitudinal" and "transverse" refer to the plane of pellet movement and are synonymous with anterior/posterior and superior/inferior, respectively. Longitudinal and transverse components of tongue blade movement were extracted from each stage. Longitudinal movement was measured in the x dimension. Transverse movement was represented by the y dimension. The tongue movements themselves were diagonal and thus contained both longitudinal and transverse movement.

Three stages of hyoid movement were observed: hyoid ascent, steady stage, and descent. Duration of each stage was determined by observing movement of the hyoid bone and its acoustic shadow. Previous research (Sonies et al. 1985) has indicated that reliability of this duration measurement is within 0.1 sec.

Total swallow duration was taken to begin at the frame before initial bolus movement and to end at the first frame of postswallow rest position for the tongue. Subjects occasionally maintained tongue-palate contact beyond the duration of the swallow until the next bolus was introduced or speech was initiated. Subjects were reminded to "let the tongue rest on the floor of the mouth after each swallow".

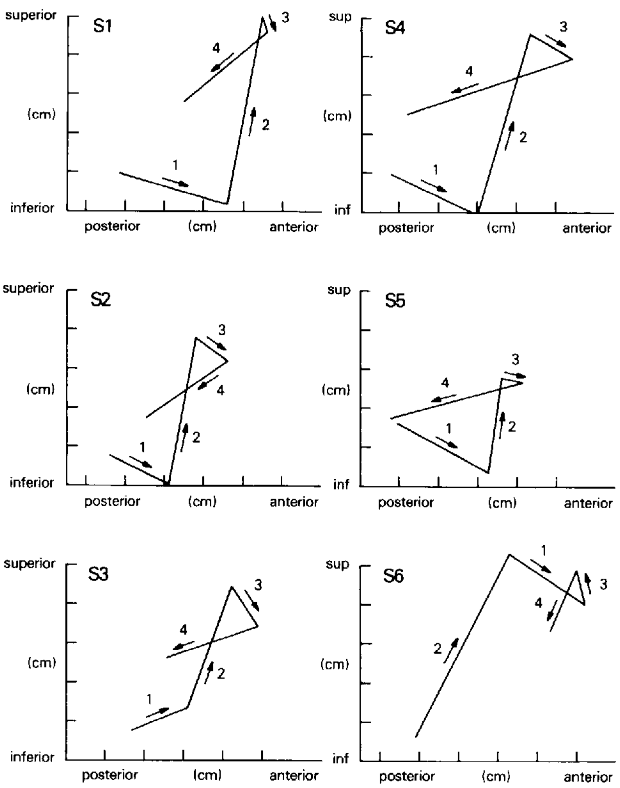

Fig. 1. Tongue blade movement for six subjects (*S1–S6*). *Arrows* show the direction and distance travelled by the pellet in each of the four stages: (1) forward, (2) upward, (3) steady, (4) downward. Note that Subject 6 produced stages (1) and (2) in reverse order.

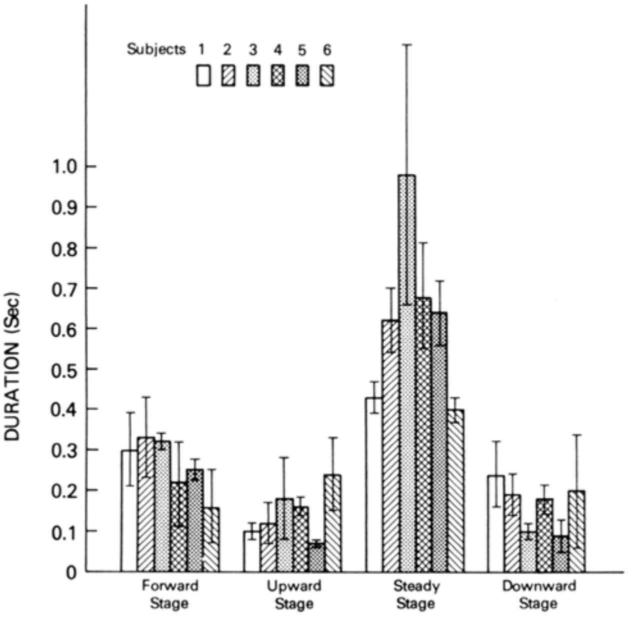

Fig. 2. Duration of each tongue blade stage for the six subjects (bars show ± 1 SD).

Results and Discussion

Pellet movement was divided into four stages as seen in Figure 1. The path of the movement was stage 1 forward, stage 2 upward, stage 3 steady, and stage 4 downward.

Subjects one through five produced a very similar swallowing pattern. During stage 1, the pellet moved forward as the bolus moved backward. Stage 2 consisted of rapid upward movement by the pellet, past the anterior border of the now posterior bolus, to the palate. This movement sealed the oral cavity anteriorly. Stage 3 was composed of a long period of tongue/palate contact (400 ± ms). A small amount of anterior tongue "drifting" (up to 5 mm) occurred during this "steady" stage. The return of the tongue to rest was the fourth stage. Postswallow rest position was almost never in the same place as the preswallow position because initially the tongue was deformed around the bolus.

A different pattern of movement was observed for Subject six. This subject produced the upward stage first. The pellet moved up toward the anterior palate. The pellet then slid along the palate toward the alveolar ridge. The third or steady stage included drifting to a slightly more posterior palatal position. The fourth stage, return to rest, was comparable to stage 4 of the other subjects. At times Subjects three and four also combined the first two stages into a single upward movement. Their averaged data, however, reflected the more typical pattern. Subject three's average pattern was most similar to Subject six's in that her initial forward movement combined anterior and superior movement. The other four subjects, on average, moved the pellet anteriorly and inferiorly as the bolus passed.

A further understanding of the swallowing movement comes from considering the duration of each stage. Figure 2 is a graph of the duration of tongue pellet movement for each stage. The first stage of movement was longer than the second for all subjects. In subjects one through five who produce movements that were similar in pattern, the forward movement of the tongue blade (stage 1) took approximately. 2 to. 3 seconds to complete and was as much as four times the length of the duration of the upward stage 2. The long duration of the forward stage was not surprising because it included the initial backward propulsion of the bolus and required precise, coordinated movement and angulation of the tongue. The steady stage of the swallow was always the longest, lasting at least one-third of the total swallow duration, with no more than 5 mm of tongue drift occuring during this stage. Stage four, return to rest, was variable in duration across subjects, possibly because rest is an unspecified position with respect to the rest of the tract and does not necessarily have any timing relationship to the rest of the swallow.

Subject six produced a similar temporal pattern to the other subjects. As mentioned above, her patern of movement at first glance was quite different from the other five subjects (Fig. 1). Her upward stage occurred first, and it was longer than the forward stage. Moreover, during the steady stage of tongue-palate contact, the tongue slid backward along the palate unlike the other subjects. This unusual pattern, however, can be explained, and indeed the reversal of the first two stages sheds light on the dynamics of tongue blade movement during the swallowing.

A close examination of the videotapes revealed that Subject six (and occasionally Subjects three and four) held the bolus in a more posterior position before swallowing than did the other subjects, causing a flatter bolus with less water anterior to the pellet. To initiate bolus movement, the blade moved upward and forward in a single gesture (Fig. 1). Because this gesture included the initial containment and propulsion of the bolus, it required the same care and precision as did stage 1 of the other subjects. Thus it also required a long duration. This is supported by the fact that, although the tongue blade did not change direction during this stage, it did pick up considerable speed after the bolus passed and directed propulsion was no longer a factor. This subject's second gesture was the rapid sliding of the tongue anterior and inferior along the palate. This movement, occurring after tongue palate contact was made, is strongly supportive of the notion that the anterior movement component is part of the swallowing pattern for some reason other than bolus propulsion. This hypothesis is discussed in detail in a subsequent section.

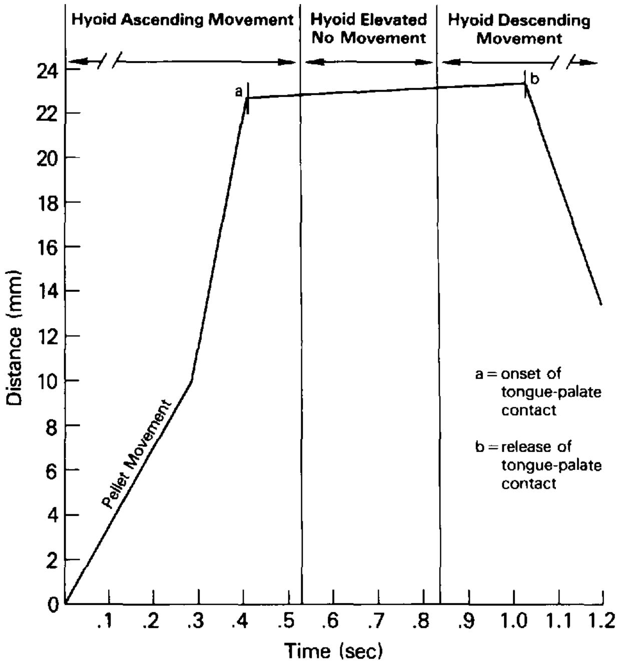

Fig. 3. Tongue pellet displacement and hyoid timing in average of 24 swallows. Distance moved indicates amount, not direction of movement.

Timing of the Tongue Blade's Movement

A comparison of timing of the tongue and the hyoid bone (Fig. 3) indicates several noteworthy relationships. First, the tongue blade was most active during hyoid ascent, i.e., the first third of the swallow. Second, tongue-palate contact occurred shortly before the hyoid reached its steady state position. Third, the steady stages of the hyoid and tongue overlapped. Finally, tongue-palate contact was not released until after the hyoid began its descent. Initial hyoid ascent is probably partially due to tongue movement up toward the palate. This movement cannot be the controlling factor, however, for two reasons. First, a person can swallow with the tongue fixed against the palate. That is, lack of tongue blade elevation does not inhibit hyoid/airway elevation. Second, in the present data, tongue-palate contact occurred from 80–220 ms before the hyoid stopped rising, again indicating hyoid elevation without tongue blade elevation. Nonetheless, these data indicate a synchrony between the timing of the tongue blade and the hyoid in the normal swallowing gesture. Both the tongue and the hyoid moved actively during the first third of the swallow, were stationary while the bolus was in the lower pharynx, and then returned to rest.

Tongue Blade Movement as a Waveform

Another way of considering tongue blade movement is as a complex waveform. As with any such waveform, tongue movement can be broken down into a transverse and longitudinal component. Longitudinal movement was seen in the anterior-posterior dimension. Transverse movement was measured in the superior-inferior dimension.

Although there were too few data for valid statistical analyses to be performed, some qualitative statements can be made about the factors that contributed to the direction and extent of the pellet's movement. Bolus positioning on the tongue was evaluated and appeared to have a major effect on the swallow waveform. The effect of the initial bolus position can be seen when comparing across subjects. Because of the posterior bolus positioning, Subjects three and six's tongue blades were maximally displaced inferiorly prior to bolus movement. Thus, all transverse movement during initial bolus propulsion was in a superior direction (Fig. 1). The other subjects typically held the bolus more anteriorly. Swallowing initiation therefore involved some movement directed inferiorly as the bulk of the bolus passed over the pellet. Thus, the initial position of the bolus on the tongue determined the direction of pellet movement during the initial stage, which in turn shaped the transverse component of the overall movement.

Longitudinal movement of the tongue blade does not intuitively appear to be necessary for swallowing. Nonetheless, all six subjects did produce anterior movement of 1 cm or more. This movement occurred during bolus passage, during upward tongue movement as the bolus was squeezed back, after tongue-palate contact was made, and during the steady tongue stage in the form of anterior tongue drifting. Some anterior movement is expected based on the radial nature of the tongue's movements (Hashimoto and Sasaki 1982; Stone et al. 1983). This radial effect appears to be evident during the upward and downward stages in which all six subjects displayed some anterior/posterior angling of the gesture (Fig. 1). The radial movement does not, however, explain the forward stage of blade movement or the slight drift during the steady stage.

A possible explanation for these movements can be made. During bolus propulsion and tongue-palate approximation, superior movement of the tongue is of primary importance. However, purely superior movement might leave the tongue blade in an awkward position when it contacts the palate. Location of tongue-palate contact is important in creating a complete anterior seal of the oral cavity. Thus, either during the initial stages of bolus movement or subsequent to tongue-palate contact, the tongue must be positioned in the anterior/posterior position that produces an optimal oral cavity seal.

Velocity was calculated for each stage from distance and duration measures of pellet movement. Table 1 indicates that during the first two stages – that is, before tongue-palate contact – the tongue moved anteriorly at an almost constant velocity for all subjects (Table 1, anterior movement, stages 1 and 2, subjects 1–6). In contrast, a large

Table 1. Pellet velocities (cm/sec) for stages 1 and 2.

Subjects	Anterior movement		Superior/Inferior movement	
	Stage 1	Stage 2	Stage 1	Stage 2
1	3.2	3.2	3.3	16.4
2	1.3	3.0	0.9	10.0
3	1.6	2.1	0.6	6.1
4	2.0	3.0	1.5	8.7
5	3.0	0.9	1.7	12.1
6	2.6	6.9	1.0	11.7

[a] Velocity was calculated, for each stage as the distance the pellet moved divided by the duration of the movement.

difference in movement velocity was seen in the superior/inferior dimension (Table 1, superior/inferior movement, stages 1 and 2, subjects 1–6). The slow, constant anterior movement appeared to relocate the tongue to a specific target position. Stage 3 data indicated that, once the preferred tongue-palate position was achieved, it was maintained with a minimum of subsequent tongue drift (Fig. 1). Presumably, the optimal position is based on some sensory endpoint (possibly the alveolar ridge or rugae). Measures of tongue-palate contact area would be needed to provide the actual location of the tongue. It is clear, nonetheless, that longitudinal tongue movement is as integral and purposeful a component of the tongue blade's movement during normal swallowing as is transverse movement.

Conclusions

The normal tongue blade gesture during swallowing requires four stages of movement. These stages contain both longitudinal and transverse components that are associated, respectively, with tongue positioning and bolus actuation. The tongue blade was most active during the first third of the swallow; that is, the first two stages. This activity was synchronous with actuation of the bolus toward the pharynx and with the ascent of the hyoid bone (thus also with larynx/airway protection). This initial tongue activity also included the greatest changes in direction and the greatest distance traveled for the entire swallow. The high maneuverability of the tongue blade allows it to perform the key functions of bolus formation, containment, and actuation while maintaining a synchrony of movement with reference to hyoid ascent.

Initial bolus containment and propulsion required careful and precise tongue activity. Thus the first tongue stage was slow regardless of the direction it took. Direction of movement for this stage depended on bolus shape and placement in the mouth. A more posterior bolus produced little or no inferior movement during bolus actuation because the tongue blade was maximally displaced inferiorly prior to swallowing. When held anteriorly, the bolus was more circular in shape, with the pellet located posterior to the point of maximal displacement of the tongue. As the bolus moved posteriorly and the tongue moved anteriorly, inferior tongue movement occurred. Once the bolus passed, the tongue very rapidly moved in a superior direction to approximate the palate. As this transverse movement was occurring, the tongue was also moving anteriorly (longitudinally). Despite the vast changes in rate occurring transversely, the longitudinal movement proceeded at an almost constant rate until some focal point on the palate was contacted. Subsequently, only minor drifting occurred until the anterior tongue-palate seal was released.

Thus, the normal swallowing gesture is complex and involves an intricate timing relationship between hyoid movement, bolus propulsion, and tongue-palate approximation. Further research is needed to determine the effect that disorders in the oral phase of swallowing will have on this relationship.

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