A New Application for Electropalatography: Swallowing

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Abstract. Electropalatography (EPG) has been applied to linguistic research and speech pathology. This study evaluated whether EPG could provide useful information on swallow-related tongue action. Specifically, the investigation focused on the quantification of tongue-palate contact patterns for swallowing and on the effects of bolus volume and consistency. Five normal subjects were tested during swallows of 5 and 30 ml of water, 5 and 30 ml of gelatin, and saliva. By segmenting the EPG time-motion sequences into four stages (prepropulsion, propulsion, full contact, withdrawal) and compartmentalizing the palate into six bins (front, central, back, lateral, medial, midline), temporal and spatial characteristics of deglutitive tongue-palate contact were revealed. Significant differences ($p < 0.01$) were found in contact timing across bolus sizes and consistencies for the propulsion and full contact stages. Water was propelled faster than gelatin, and 30-ml gelatin faster than 5-ml gelatin. Dry swallows had a longer full contact stage than water. Contact patterns, though not statistically analyzed at this time, appeared to vary little as a function of bolus properties. Our findings suggest potential value in using EPG to investigate the timing and patterning of abnormal tongue movements associated with disordered swallowing.

Key words: Deglutition — Deglutition disorders — Electropalatography — Tongue — Tongue-palate contact — Bolus volume — Bolus consistency.

The tongue has long been recognized as the “principal mobile agent” for oral and oropharyngeal transport of the bolus during swallowing [1]. In recent years there has been empirical evidence that oropharyngeal bolus propulsion is the product of tongue pumping action supplemented by pharyngoesophageal pressure change [2,3]. In addition, there have been new data on the kinematic and/or biomechanical relationships between lingual activity and bolus volume [4–6]. Kahrilas et al. [5], in particular, have demonstrated that the tongue modulates its surface contour to accommodate different bolus sizes, i.e., the larger the bolus, the deeper the central groove. They have further reported that larger volumes have more vigorous bolus expulsion from the oropharynx. Despite recognition of the tongue’s vital role in enacting swallow-related physiological events, our understanding of deglutitive lingual motor strategies and the effects of bolus properties (volume and consistency) on tongue action is far from complete.

Structurally as well as functionally, the tongue possesses diverse and unique properties. It is capable of performing a wide range of movements with multiple degrees of freedom because of the remarkable muscular-hydrostatic characteristic of its composition [7] and because of the structural constraints of the oral cavity, especially that imposed by the hard palate [8]. Conceivably, tongue-palate contact during swallowing not only provides the anterior and lateral seals necessary for bolus containment, but also is a source from which the tongue can gain stability, expand its motility, alter its surface contours, generate pressure gradients, as well as derive the force needed for bolus propulsion. To date, linguopalatal coordination in the context of swallowing has not been studied in detail using electropalatography (EPG).

EPG has been used to examine the location, pattern, and timing of linguopalatal contacts during normal and disordered speech. Its prevalent applications are in linguistics and speech pathology. Linguistic research has studied phoneme-specific contact characteristics and lingual coarticulatory effects in different languages (see [9]).
for review). In speech pathology EPG has been used as a biofeedback tool in articulatory remediation [9,10]. In recent years there have been increasing efforts in devising EPG data reduction methods for quantitative analysis of speech-related lingual behaviors [11-14]. In contrast to its established usefulness in speech research and therapy, EPG has not been applied to the study of nonspeech lingual motor behaviors such as those occurring during swallowing.

The objective of this study was to determine if EPG could provide useful information on the spatial and temporal aspects of swallow-related tongue action. Specifically, the following questions were asked:

1. Can tongue-palate contact patterns be quantified in a way that captures oral-cavity swallowing behaviors?
2. Does deglutitive tongue-palate contact differ in timing or pattern as a function of bolus properties?

Materials and Methods

Subjects

Five normal adults, 3 female and 2 male, between 23 and 47 years of age, served as subjects (S1 to S5). They presented no history or complaints of swallowing problems, and all passed a swallowing screening and an oromotor screening.

EPG Instrumentation

EPG data were collected using a Kay Elemetrics Palatometer System (Model 6300, Lincoln Park, NJ). The Kay Elemetrics Computerized Speech Lab (Model 4300) was used to simultaneously record the "trigger signals"—a click from a noise maker followed immediately by a glottalized "a". The click cued the subject to begin swallowing. Both signals facilitated the identification of swallow onset on the Palatometer display during analysis.

Each subject wore a custom-fitted, 0.5-mm thick, molded acrylic pseudopalate containing 96 electrodes that were symmetrically embedded along the medial surface of the teeth (ensuring maximum width) and across the plane of the hard palate. Pseudopalate length was maximal for each subject, extending 5–10 mm beyond the third molars, but short of the gag reflex mechanism. The distance between the electrodes was normalized across palates relative to the subject’s dentition and palate size. Extending from each electrode was a fine wire (42 gauge), and the wires were gathered at the back of the pseudopalate in left and right bundles. The bundles were routed around the molars and anteriorly along the lateral teeth to exit the mouth at the front. They were then attached to the I/O box of the Palatometer via connectors. The overall electrode threshold was adjusted for the individual subjects to a range determined in multiple pilot studies to be sensitive to tongue contact but insensitive to the bolus itself. Occasionally, flickering of the electrodes occurred, especially when the bolus was held in the mouth preparatory to swallowing. Flickering was the apparent loss of contact for a single frame. This was an artifact due to the sensitivity of the equipment and was ignored in the data analysis.

Prior to data collection, each subject wore the pseudopalate for at least 20 minutes during set-up procedures. This allowed adaptation to the palate’s presence and to the loss of palatal sensory feedback. Previous research indicated that thin (1-mm thick) artificial plates did not affect normal articulation after only a few minutes of acclimatization [15]. No research has investigated the effects of sensory-feedback loss due to an acrylic pseudopalate. In the present study, subjects were queried before and throughout data recording about palatal comfort and swallowing ease. No discomfort or difficulties were reported, although it is possible that the pseudopalate had a minimal effect on swallowing.

For each swallow performed, tongue-palate contact information was collected at a sweep rate of 100 samples per sec for a total of 4 sec (instrument’s limit). This information was relayed to the computer, displayed on the monitor in a layout closely resembling the actual electrode placement, and stored on a hard disk. The acoustic waveform of the trigger signals, time-linked to the contact data, was also displayed.

Materials and Procedures

There were five swallowing tasks in the experimental design; including two bolus volumes and three bolus consistencies. The five tasks were (1) 5 ml of water, (2) 30 ml of water, (3) 5 ml of gelatin, (4) 30 ml of gelatin, and (5) dry swallow. Although it has been shown that the average size of a normal thin liquid bolus is 21 ml [16], the quantity of 30 ml was chosen in this study to maximally contrast volume difference. This decision was further supported by Hamlet’s x-ray microbeam study of swallowing in which inconsistent effect of water-bolus size (5, 10, 15 ml) on tongue position, grooving, and velocity was attributed to the small volume differences [4]. In the present study, 30 ml of water was handled successfully by all subjects, but during the postexperiment interviews 2 subjects reported that the 30 ml of gelatin, though manageable, “felt funny” or “strange” when swallowed at once.

Each swallowing task was repeated six times in a completely randomized presentation sequence. Dry swallows were accomplished by swallowing the saliva present in the mouth at the time. In the event of two successive dry swallows, a between-task delay of at least 15 sec was introduced.

Water and gelatin were presented in syringes. Jello-like boluses were prepared with unflavored gelatin (Knox), sugar, water, and red food coloring. The use of plain gelatin was necessary to avoid acid-induced activation of electrodes. For the gelatin swallows, the syringes were pretreated by removing the protruded tips and creating a hole (6 mm in diameter) at the center of the flat, sanded head. This allowed the gelatin to be coarsely mashed while being squirmed into the mouth, thus eliminating mastication.

For each swallow, the subject was instructed to keep the tongue in the lowest possible position, hold the bolus anteriorly in the mouth without movement, clear the entire bolus in one swallow upon hearing the trigger click, and open the mouth slightly after swallowing. These requirements ensured stable, minimal tongue-palate contacts at the start and finish so that activity onset and termination could be identified without ambiguity.

Data Analysis

A total of 149 out of 150 swallows were analyzed. One 30-ml gelatin swallow from S5 was excluded because the subject cleared the bolus in two consecutive swallows. Two features were measured for each swallow: timing of component stages and contact patterns across different palatal regions.

Timing

Preliminary examination showed that the EPG swallowing time series, though representing a continuous physiological event, contained four