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Physiologic Model of Oropharyngeal Swallowing Revisited

Bonnie Martin-Harris, PhD, Yvonne Michel, PhD, and **Donald O. Castell, MD,** Charleston, South Carolina

OBJECTIVE: The purposes of this investigation were to determine whether the temporal onsets of swallow events segment into oral and pharyngeal phases, to test the interdependence of temporal onsets of swallow events, and to determine the influence of age on total swallow duration.

STUDY DESIGN AND SETTING: The onsets of swallowing and respiratory measures were studied in 76 healthy normal individuals.

RESULTS: Confirmatory factor analysis revealed a 2-factor solution but did not support the hypothesized 2-phase structure (ie, oral and pharyngeal). Two of the onsets, apnea onset and apnea offset, formed a single factor that explained 12.6% of the variation among the 11 onset times. The other 9 onsets formed a second factor that explained 66.4% of the variation. Age accounted for modest variation in total swallow duration.

CONCLUSIONS: The two factors, oropharyngeal and respiratory, explained 79% of the variation among the 11 onset times.

SIGNIFICANCE: This finding speaks to the overlap between the initiation of oral and pharyngeal components of swallowing in adults and highlights the artificiality of separating the swallowing continuum into isolated phases.

Swallowing has been historically described as occurring in stages or phases. These phases include: (1) oral phase, (2) pharyngeal phase, and (3) esophageal phase.[1,2] The remaining discussion will be limited to the oral and pharyngeal phases of swallowing because the scope of the study was limited to oropharyngeal swallowing dynamics. The use of the phases to explain oropharyngeal swallowing has been based primarily on visual observations and temporal measurement of structural movements and bolus flow throughout the upper aerodigestive tract from lateral videofluorographic recordings.[1-3] The addition of simultaneously recorded manometric pressure events added to the body of knowledge regarding swallowing physiology and demonstrated that physiologic events during swallowing are interdependent, that is, one event impacts another.[4-8] An example of this interdependence is the pulling away of the posterior cricoid cartilage from the posterior pharyngeal wall via superior and anterior excursion of the hyoid and larynx. Relaxation of the cricopharyngeal muscle, combined with these biomechanical actions, results in opening of the pharyngoesophageal segment (PES) and permits bolus passage into the esophagus. The combined, two-dimensional manometric and fluorograhic image analyses also resulted in the ability to associate the structural movements of the upper aerodigestive tract with the pressures or propulsive forces applied to the bolus during deglutition.[4-8] The application of digital image analysis has furthered the understanding of swallowing physiology from combined manometry and videoradiography. This analysis system involves calculations of relative distance measures based on the movement of structures such as the tongue, hyoid, and larynx from 2-dimensional images.[9,10] Questions remain, however, regarding the suitability of using temporal or

From the Medical University of South Carolina, Department of Otolaryngology–Head and Neck Surgery (Dr Martin-Harris), Evelyn Trammell Institute for Voice and Swallowing (Dr Martin-Harris), Medical University of South Carolina, Department of Communication Sciences & Disorders (Dr Martin-Harris), Saint Joseph's Hospital of Atlanta, Evelyn Trammell Voice and Swallowing Center (Dr Martin-Harris), Medical University of South Carolina, College of Nursing (Dr Michel), and Medical University of South Carolina, Department of Gastroenterology and Hepatology (Dr Castell).

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Reprint requests: Bonnie Martin-Harris, PhD, Medical University of South Carolina, Department of Otolaryngology–Head and Neck Surgery, 135 Rutledge Avenue, PO Box 250550, Charleston, SC 29425.

E-mail address: harrisbm@musc.edu.

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distance measurements from videofluoroscopy alone, a 2-dimensional, moving, radiographic image to assess the function of a 3-dimensional system. Nevertheless, temporal measures made from videofluorscopic images continue to be prevalent in the literature as a standard for quantifying swallowing impairment. It has been assumed that aberrations from "normal" timing will relate to the presence and severity of the overall deviation in swallowing function. These temporal measures have included combined onsets and durations of individual physiologic components of swallowing such as hyoid excursion, laryngeal closure, opening of the PES, apneic swallow interval or bolus flow measures such as, oral transit time, pharyngeal transit time, pharyngeal swallow delay time, and total swallow duration.[1-3,11] Temporal physiologic measures are based on movements of structures in the upper aerodigestive tract during swallowing, whereas bolus flow measures relate to the position of the bolus in time during the swallow. Studies also have demonstrated how alterations in timing of structural movement and bolus flow explain variation in the swallow mechanism. An example is the presence and severity of laryngeal vestibular penetration.[11,12] It follows that delays or prolongations of events should contribute to extended oropharyngeal swallow durations defined as the time from the onset of oral bolus transport, a bolus flow measure, to the completion of movement (ie, rest) of the hyolaryngeal complex, a temporal physiologic measure.

The overall relevance of onsets of individual swallow events to the composite event, total swallow duration, has not been tested in a large sample of healthy adults across the aging continuum. Further, it has not been shown whether the temporal measures separate into true oral and pharyngeal phases, the traditional nomenclature used to describe swallowing function.

The purposes of this investigation were to:

- Determine whether the temporal onsets of swallow events segment into oral and pharyngeal phases of swallowing.
- Test the interdependence of the temporal onsets of swallow events.
- Determine the influence of aging on swallow duration.

METHODS

Participants

The study protocol was submitted for full review and approved by the Institutional Review Board at Medical University of South Carolina. Human volunteers were used for this study. Written informed consent was obtained from each study participant. Medical and surgical history and medications were obtained via patient interview and written survey. Volunteers with histories of the following upper aerodigestive tract surgeries were excluded from study participation: oral, nasal, pharyngeal (including uvulopalatopharyngoplasty [UP3]), laryngeal, and esophageal resections. Exclusion criteria also included known history of swallowing disorders, dysphagia, hiatal hernia, chronic indigestion, gastroesophageal reflux disease (GERD), pulmonary disease, cancer of the head and neck, neurological disease, current medications with known effects on swallowing or breathing, or tobacco use during the past 10 years. Patients were not excluded if they had history of tonsillectomy, adenoidectomy, or sinus surgery.

Eighty-two participants were enrolled in the study and comprised 4 age groups. Group I (n = 21) included 11 males and 10 females, 12 whites and 9 nonwhites with a mean age of 31 years (range = 21 to 40 years). Group II (n = 21) was comprised of 11 males and 10 females, 11 whites and 10 nonwhites with a mean age of 48 years (range = 41 to 59 years). Group III (n = 19) had 9 males and 10 females, 10 whites and 9 nonwhites with a mean age of 72 years (range = 61 to 80 years). Finally, group IV had 6 males and 15 females, 15 whites and 6 nonwhites with a mean age of 86 years (range = 81 to 97 years).

Instrumentation

A high resolution, dual modality, videofluoroscopic and nasal airflow recording device was used for signal acquisition and digital storage of respiratory related airflow and swallowing data (*Digital Swallowing Workstation*, model 7100, Kay Elemetrics, Lincoln Park, NJ). Nasal airflow was captured using a standard, 7-foot nasal cannula coupled to the *Workstation* using the *Swallow Signals Lab* hardware and software to create a digital display of the respiratory phase and the swallow apnea duration, operationally defined as the period of nasal airflow cessation. The nasal cannula was calibrated immediately before the study of each participant to ensure accurate measures. Airflow direction was shown on the respiratory display with a green trace representing expiration (positive polarity) and a red trace representing inspiration (negative polarity). The apneic period was depicted as the flat, black respiratory trace along the abscissa (Fig 1).

The sampling rate for the respiratory tracing was 250 Hz. This was considered an acceptable sampling rate for detecting breathing that occurs an average of 10-12 times per minute in nonimpaired adults. Videofluoroscopic recordings were made with a resolution of 60 fields (30 frames) per second. The resolution for determining measurements using digital video recordings, therefore, was 16.6 ms per digital field. Simultaneous videofluoroscopy and respiratory airflow recording was conducted in a standard fluoroscopy suite. Tight coning of the x-ray beam limited radiation exposure to the superior structures of the aerodigestive tract (ie, oral cavity, pharynx, larynx, and cervical esophagus). Participants were positioned in the lateral viewing plane while standing and self-administered 2 trials of 5-mL liquid boluses of barium sulfate contrast solution (Liquid Barosperse Barium Sulfate Suspension, catalogue no. 179364, Lafayette Pharmaceuticals, Anaheim, CA) per 50 ml graded medicine cup. This conservative volume was chosen to simulate a safe bolus size typically administered to dysphagic patients during a videofluoroscopic examina-