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Coordination of oro-pharyngeal food transport during chewing and respiratory phase

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HIGHLIGHTS

- Onset of Stage II transport and swallowing cycles was predominantly during expiration.
- Onset of chewing cycles was comparatively less often during expiration.
- Neural control of respiratory phase varies among these three feeding behaviors.
- Expiratory airflow during stage II transport may reduce prandial aspiration.

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ABSTRACT

When eating solid food, the tongue intermittently propels triturated food to the oropharynx or valleculae, where a bolus accumulates before swallowing. The tongue motion during this food transport (stage II transport, STII) is distinctly different from that during chewing, and is more similar to the oral propulsive stage of swallowing. Therefore, we tested the hypothesis that the onset of STII cycles was more likely to occur during expiration than inspiration. Videofluorography was recorded in a lateral projection while 10 healthy subjects ate solid foods. Respiration was concurrently monitored with plethysmography. Jaw motion cycles were classified as masticatory or swallowing. Masticatory cycles were further divided into chewing cycles and STII cycles. STII cycles were defined as those with bolus propulsion through the fauces by the tongue squeezing against the palate (without swallowing). Overall, 28% (62/223) of chewing cycles were initiated during inspiration, compared with only 12% (9/76) of STII cycles in this phase. The fraction of masticatory cycles occurring during inspiration was significantly smaller for STII cycles than for chewing cycles (Odds Ratio: 0.37 [95% CI: 0.17–0.78], $p = 0.01$). All 36 swallowing cycles had onset during expiration. Our findings reveal that stage II oro-pharyngeal food transport is linked to expiration, as is the oral propulsive stage of swallowing. This suggests a similarity in the neural control of these two feeding behaviors.

1. Introduction

The pharynx is a common passage for breathing and eating but is used in different ways. The pharynx is dilated to maintain airway patency for breathing, but for swallowing, the pharynx is constricted to push the food bolus propelled from the oral cavity to the esophagus. Respiratory phases surrounding swallowing are well controlled by the central nervous system to prevent inhalation of food and drink during swallowing; indeed, there is a pause in breathing during the swallow. A number of studies, using various measurement systems and different food consistencies, confirm that onset of swallowing is usually during expiration and breathing resumes in expiration after swallowing. Thus, the predominant respiration–swallowing pattern for a single liquid bolus swallow in adult humans is "exhale–swallow–exhale" (67–79% of liquid swallows), followed by "inhale–swallow–exhale" (18–21%) [1–3]. When eating solid food, swallowing is predominantly initiated during expiration (87–99%) [4–6].

Except for crucial moments surrounding the swallow, mastication and respiration have an inconsistent temporal relationship. When eating solid food, the tongue squeezes triturated food back along the palate to the oropharynx or valleculae, where a bolus is formed for up to 10 s before onset of swallowing. The food accumulating in the oropharynx is located in the path of respiratory airflow during mastication; this

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could potentially increase the risk of aspiration. Indeed, air can be inhaled through the pharyngeal airway while food is but a few millimeters above the laryngeal aditus. However, our previous study revealed that there is no consistent phase of respiration during the period of bolus aggregation in the pharynx [5]. There can be inspiration, expiration, or a pause in breathing during bolus aggregation, and in some cases there are multiple respiratory cycles during a single period of bolus aggregation in the pharynx.

The transport of a bolus of chewed and softened food from the oral cavity to the oropharynx during chewing is called stage II transport (STII) [7]. The tongue motion of STII is similar to the motion for the oral propulsive stage of swallowing and quite different than that for chewing. For chewing, the tongue shifts and rotates toward to the working side of the jaw to place the food on the occlusal surface of the lower teeth, but in STII, the tongue surface moves directly upward to contact the palate beginning with the anterior tongue and progressing posteriorly [8,9] much as it does for the oral propulsive stage of the swallow. For liquid swallowing, oro-pharyngeal bolus transport is thought to be a part of a consecutive swallowing process that is regulated by the medullary swallowing center. Swallowing is usually initiated during expiration both when drinking a liquid bolus and when eating solid food [4,5,10]. The relationship between stage II transport and phase of respiration has not been reported. In the present study, we tested the hypothesis that stage II transport is more frequent during expiration than inspiration while feeding on solid food.

2. Materials and methods

2.1. Data acquisition

The study protocol was approved by the Institutional Review Board (Application No. 86-06-25-03). Ten healthy, asymptomatic young adults (6 men, 4 women, median age: 25 yrs., range: 18–39 yrs.) participated after giving written informed consent. Dental occlusion was Class I in all subjects. Subjects were seated comfortably in a chair and ate 6 g each of banana and shortbread cookie lightly coated with barium powder while videofluorography (VFG) at 30 fps was recorded on a digital-video (DV) tape recorder in a lateral projection. The average X-ray exposure duration during a single trial was 13.1 ± 3.5 s (mean $\pm$ SD) for banana and 25.2 ± 4.8 s for cookie, respectively.

Respiration was monitored concurrently with a respiratory plethysmograph (Respitrace, Nims, North Bay Village, FL). Plethysmograph bands were placed around the chest and abdomen. Respiratory signals were collected on a digital data recorder (LX-10, TEAC, Montebello, CA) and a laptop computer at a 1 kHz acquisition rate.

A trigger switch box (Event & Video Control Unit, Peak Performance Technologies, Inc., Centennial, CO) was connected to the digital data recorder and the DV tape recorder. Depressing the trigger button generated a square-wave spike signal that was recorded on the digital data recorder and simultaneously created a distinctive square flash image on the VFG video image recorded by the video recorder. The respiratory data and VFG images were then synchronized by matching the timing of the spike signal from the respiratory record with the time of the square signal on the VFG recording.

2.2. Data reduction

2.2.1. Feeding

The VFG images on DV tapes were converted to digital image files (with no image compression), and stored in the PC using video editing software (Adobe Premiere, Adobe System Inc., San Jose, CA). Each recording included a VFG recording of a complete feeding sequence from ingestion of each food to the terminal swallow. A feeding sequence was divided into jaw motion cycles starting at one minimum gape and ending at the next. The minimum gape was defined as the end of visible upward movement of the lower jaw on the VFG recording. Each cycle was then classified as a masticatory cycle or a swallowing cycle. A swallowing cycle was defined as a jaw motion cycle during which a swallow occurred (defined as contraction of the pharynx with bolus transport though the upper esophageal sphincter). A masticatory cycle was defined as a jaw motion cycle with no swallowing. Masticatory cycles were further divided into chewing cycles and STII cycles. STII cycles were defined as jaw motion cycles with bolus propulsion through the fauces by the tongue squeezing against the palate, as described previously (Fig. 1) [11]. A STII cycle, by definition, did not include a swallow.

Respiratory data were recorded as the weighted sum algorithm of the chest and abdomen change on the plethysmograph. The algorithm to calculate the weighted sum was created by the developed company, and was not disclosed. Then, the respiratory data were processed with digital signal analysis software (DADiSP 2002, DSP Development, Boston, MA). To minimize high frequency noise of the plethysmograph data, the three window moving average was used. The interval of the three data points was 3/1000 s. One VFG image has 1/30 s duration and we estimated that the three-point window moving average had little if any influence on the respiratory phase detection for each jaw motion cycle. The times of the start and end of each inspiration were extracted from the plethysmograph data using a semi-automatic peak detection function of the software. The inspiratory phase was defined as the time from the onset of inspiration to the end of inspiration, and the expiratory phase was defined as the time from the end of inspiration to the onset of the next inspiration.

2.3. Data analysis

We determined for each jaw motion cycle whether its onset was during inspiration or expiration. The incidence of jaw motion cycles initiated during inspiration or expiration was then calculated for each type of jaw motion cycle (chewing, STII, or swallowing). We tested whether the fraction of masticatory cycles initiated during inspiration differed between chewing and STII cycles (using the Mantel–Haenszel test).

As feeding (eating and swallowing) is a sequential process, the conditions of one phase may have influenced the subsequent one. Therefore, we also examined whether the jaw motion cycle following each STII transport cycle was less likely to occur during inspiration using the Mantel–Haenszel test.

The critical value for rejecting the null hypothesis was $\alpha < 0.05$. Statistical analyses were performed with SPSS 20.0 software (SPSS Inc., Chicago, IL).

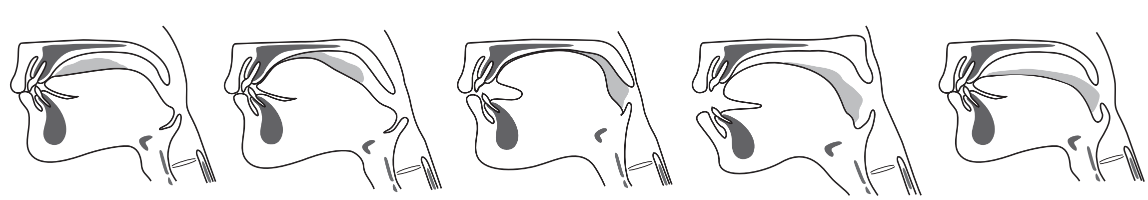

Fig. 1. Definition of the stage II transport cycle. Drawings are based on a videofluorographic recording. The drawings are partially modified from original drawings [11]. The triturated food is placed on the dorsal surface of the tongue after jaw closing, and then propelled to the oropharynx over the posterior nasal spine by a tongue squeezing motion.