Tohoku J. Exp. Med., 2015, **236**, 39-43

Isolated Pharyngeal Swallow Exists during Normal Human Feeding

Hitoshi Kagaya,[1] Michio Yokoyama,[1] Eiichi Saitoh,[1] Daisuke Kanamori,[1] Chiaki Susa,[1] Rebecca Z. German[2] and Jeffrey B. Palmer[3]

[1]Department of Rehabilitation Medicine I, School of Medicine, Fujita Health University, Toyoake, Aichi, Japan
[2]Department of Physical Medicine and Rehabilitation, Johns Hopkins University, Baltimore, MD, USA
[3]Department of Otolaryngology, Head and Neck Surgery, and Center for Functional Anatomy and Evolution, Johns Hopkins University, Baltimore, MD, USA

Swallowing is one of the basic activities in humans. The pharynx functions as an airway and a food channel, and a pharyngeal swallow usually occurs after bolus transport from the oral cavity. However, direct fluid infusion through a catheter into the hypopharynx produces a pharyngeal swallow without the oral stage in experimental situations. The purpose of this study was to examine whether a pharyngeal swallow, which is not accompanied by bolus transport, can occur during normal human feeding. Fifty-three healthy volunteers (25-89 years) were recorded, via videofluoroscopic examination of swallowing, during 3 different swallowing trials: command swallow of 10 ml liquid barium, chew-swallow of corned beef, and chew-swallow of a mixture of corned beef and liquid barium. Subsequently each swallow was classified as being either a consecutive pharyngeal swallow (CPS), following transport, or an isolated pharyngeal swallow (IPS), without immediately prior transport. The location of the bolus at swallow initiation was also noted. Of 307 trials, 681 swallows were identified, which included 43 IPS and 638 CPS. IPS only occurred as the first swallow of a trial, but the frequency of IPS did not differ between 28 younger (< 60 years) and 25 older (≥ 60 years) people. Of the three food types, IPS occurred more frequently with the mixed food than with liquid. These results suggest that IPS may represent an airway protective mechanism. In conclusion, IPS occurs in normal swallowing during a daily eating situation. Swallowing is more complex than a simple reflex.

Keywords: consecutive pharyngeal swallow; deglutition; isolated pharyngeal swallow; model; videofluoroscopic examination of swallowing
Tohoku J. Exp. Med., 2015 May, **236** (1), 39-43.

Introduction

Swallowing is a basic biological activity that is essential for life. The bolus is propelled from the oral cavity into the esophagus via pharynx. The larynx and pharynx elevate, the larynx closes and the palatopharyngeal isthmus is sealed during pharyngeal stage of swallowing (Palmer and Hiiemae 1997). Two models of swallowing are widely recognized in drinking and eating in humans. The first is the four-stage sequence model that corresponds to command, or discrete swallowing of liquids (Linden et al. 1989; Dodds et al. 1990; Feinberg 1993) and the second is the process model that accounts for the chewing and swallowing of solid food (Palmer et al. 1992, 1997; Palmer 1998; Hiiemae and Palmer 1999). In both of these swallowing models, the pharyngeal swallow occurs after the oral stage, i.e., using propulsion by the tongue, the bolus is transported from the oral cavity through the pharynx into the esophagus. This consecutive pharyngeal swallow (CPS) occurs after the transport. In contrast, direct fluid infusion through a catheter into the hypopharynx can produce a pharyngeal swallow that was not preceded by the oral phase in both animal and human experiments (Nishino 1993; Shaker 1995; Pouderoux et al. 1996; Thexton et al. 2007). A significantly larger volume of liquid is required to trigger a pharyngeal swallow in the elderly (Shaker et al. 1994).

Swallows triggered by direct stimulation of the pharynx are different from volitional or swallows that are part of an ongoing feeding sequence swallows by not inducing sequential contact of the posterior tongue with the hard palate. An isolated swallow without prior intraoral transport is known in decerebrate animals (German et al. 2009). However, it is still unclear whether or not this isolated pharyngeal swallow (IPS), which is not accompanied by bolus transport from the oral cavity, occurs during normal human feeding. We tested two hypotheses in this paper. First was

Received February 2, 2015; revised and accepted April 21, 2015. Published online May 2, 2015; doi: 10.1620/tjem.236.39.
Correspondence: Hitoshi Kagaya, M.D., DMSc, Department of Rehabilitation Medicine I, School of Medicine, Fujita Health University, 1-98 Dengakugakubo, Kutsukake, Toyoake, Aichi 470-1192, Japan.
e-mail: hkagaya2@fujita-hu.ac.jp

that an IPS existed in normal human feeding. The second was that age and the bolus type influenced the frequency of occurrence of IPS.

Subjects and Methods

The study subjects were 53 healthy volunteers who had no history of neurologic or otolaryngologic diseases that would cause dysphagia. Written informed consent was obtained from all subjects. Subjects were divided into two groups according to age (younger group, < 60 years of age; older group ≥ 60 years of age). The younger group was comprised of 28 subjects (16 men, 12 women) with a median age of 42 years (25-57 years) and the older group was comprised of 25 subjects (17 men, 8 women) with a median age of 70 years (61-89 years). The study protocol was approved by the Institutional Review Board at Fujita Health University.

Subjects were seated comfortably upright on an examination chair and the videofluoroscopic examination of swallowing (VF) was performed at 30 frames/s in lateral projection. Subjects underwent 3 types of swallow trials as follows: 1) command-swallow of 10 ml 50% w/v liquid barium (LQ); 2) chew-swallow of 8 g corned beef (CB); and 3) chew-swallow of a two-phase mixture of 5 ml 50% w/v liquid barium and 4 g corned beef (MX). In LQ trials, 10 ml 50% w/v liquid barium was placed in the oral cavity using a syringe after which the subjects were instructed to swallow. In CB trials, 8 g corned beef containing powdered barium was placed in the oral cavity and the subjects were instructed to eat freely. In the MX trials, 4 g corned beef was placed in the oral cavity and 5 ml liquid barium was infused into the oral cavity, and then subjects were instructed to eat. Each trial started when the subject received instructions (to swallow or to eat), and ended when the subject indicated they were finished. Thus, each trial was one "serving" of food or liquid or both.

Two types of swallow were identified during review of the films. The first type is CPS. This was a pharyngeal swallow occurring after transport of the food bolus by the tongue. The second type, IPS, was a pharyngeal swallow in which the food bolus was present on the surface of the tongue, yet transport of the food bolus by the tongue did not occur. We counted the occurrence each type of swallow, and measured the position of the leading edge of bolus at swallow onset, defined as the moment when the hyoid bone began its rapid upward and forward elevation. The position of the leading edge of bolus at swallow onset was classified into one of three categories according to the location of the leading edge of the food bolus: oral cavity; the area from the incisor teeth to the posterior nasal spine, pharynx: the area from below the posterior nasal spine to the vocal cords, and pyriform sinus: the pyriform sinus beyond the vocal cords.

To confirm inter-rater reliability, three clinicians, each of whom had 2 or more years of experience in analyzing VF images evaluated independently all VF images and judged the images as either CPS or IPS. Two weeks after the initial evaluation, one clinician re-classified the same images, distinguishing between CPS and IPS to test for intra-rater reliability.

Statistical analysis

Statistical comparisons were performed with the chi square test and the Mann-Whitney *U* test. The intra-class correlation coefficient was also calculated to know inter-rater and intra-rater reliability. All analyses were performed using SPSS version 19 statistical package (IBM Corporation, Armonk, NY, USA) with *p*-values less than 0.05 being considered significant.

Results

Subjects included 53 volunteers. Each bolus was tested twice, but the swallows could not be clearly identified as CPS or IPS in some VF recordings; those trials were excluded. A total of 307 trials were included in the analysis (102 LQ, 104 CB and 101 MX). Individuals frequently swallowed several times in a single trial. As a result, a total of 681 pharyngeal swallows were observed (169 by LQ, 242 by CB and 270 by MX). The average number of swallows in a single trial was 1.70 ± 0.87 for LQ, 2.43 ± 1.10 for CB, and 2.95 ± 1.15 for MX (mean ± SD). The maximum number of swallows was 6 for LQ and CB and 5 for MX. Of the 681 pharyngeal swallows, 43 were IPS and

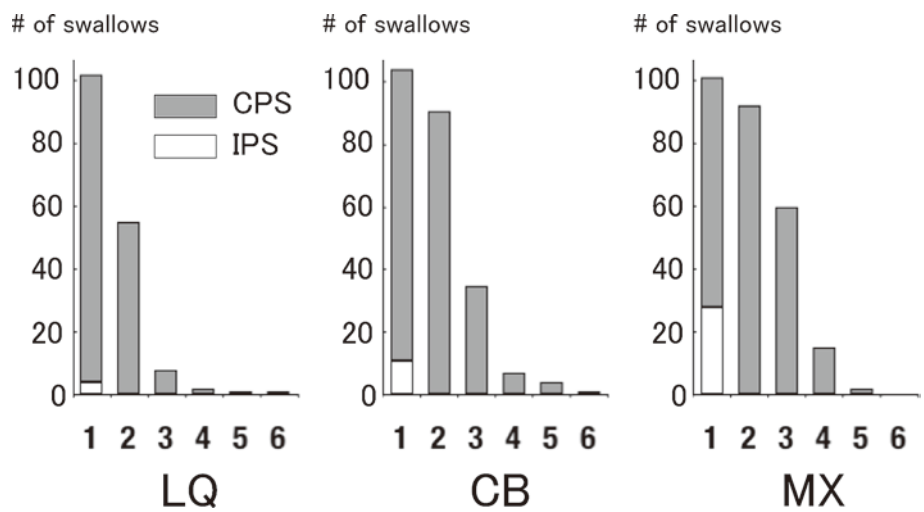

Fig. 1. Number of swallows in a single trial. IPS only occurred as the first swallow in a feeding trial; all second and subsequent swallows were CPS. The maximum number of swallows was 6 for LQ and CB and 5 for MX. CPS, consecutive pharyngeal swallow; IPS, isolated pharyngeal swallow; LQ, command-liquid swallow; CB, corned beef-chew swallow; MX, mixture of liquid and corned beef-chew swallow.

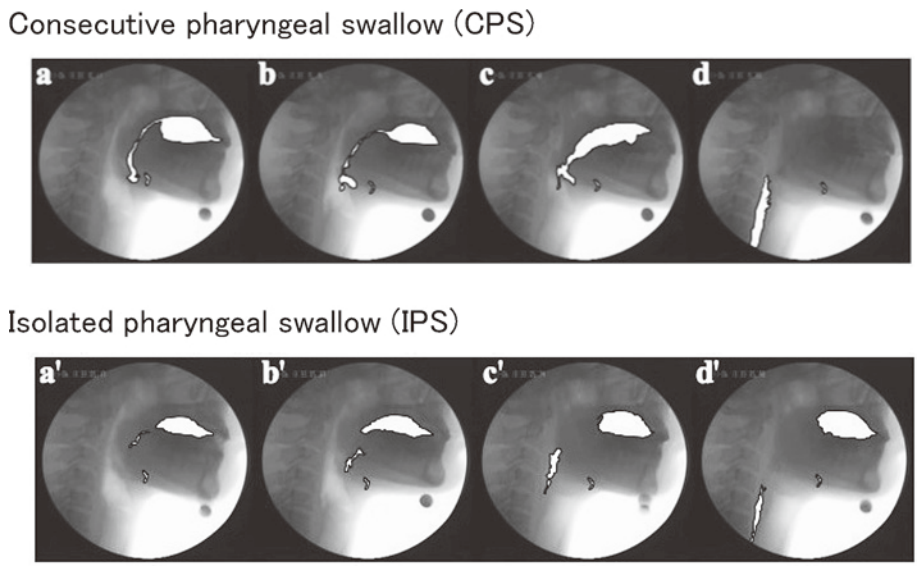

Fig. 2. Dynamic videofluorographic images of consecutive pharyngeal swallow (CPS) and isolated pharyngeal swallow (IPS). The circumference of the food bolus is outlined in black. CPS is followed by progressive transport of food bolus into the pharynx, while IPS has no transport of food bolus by the tongue preceding the swallow reflex. A small amount of food bolus is transported by gravity.
a, a′: leading edge of food bolus is across the inferior margin of the lower mandible.
b, b′: onset of superoanterior elevation of the hyoid bone, which corresponds to the onset of swallow reflex.
c, c′: 1/3 seconds after the onset of swallow reflex.
d, d′: maximum elevation of the hyoid bone.

Table 1. Frequency of IPS and CPS in the initial pharyngeal swallow.

	LQ	CB	MX	total
IPS	4	11	28	43
CPS	98	93	73	264
total	102	104	101	307

IPS, isolated pharyngeal swallow; CPS, consecutive pharyngeal swallow; LQ, command-liquid swallow; CB, corned beef-chew swallow; MX, mixture of liquid and corned beef-chew swallow.

Table 2. Position of the leading edge of foods at swallow onset.

	oral cavity	pharynx	pyriform sinus	total
IPS	0	29	14	43
CPS	25	212	27	264
total	25	241	41	307

IPS, isolated pharyngeal swallow; CPS, consecutive pharyngeal swallow.

638 were CPS. All of the 43 IPS occurred as the initial pharyngeal swallow (Fig. 1). Examples of VF images of CPS and IPS are shown in Fig. 2. Of 307 initial pharyngeal swallows, IPS was observed in 20 (12.1%) of 165 trials in the younger group and 23 (16.2%) of 142 trials in the older group, indicating no significant difference in IPS frequency between the two groups ($P = 0.305$). Thus, for all subsequent analyses, the ages were considered as one group. The frequency of IPS in the initial pharyngeal swallow significantly differed among the food-types ($P < 0.001$) (Table 1). From the value of the adjusted residual, IPS was least frequent with LQ and most with MX.

IPS did not occur when the position of the leading edge of foods was in the oral cavity. It did occur in 29 (12.0%) of 241 trials in which the bolus was in the pharynx and 14 (34.1%) of 41 trials in which the bolus was at the level of the pyriform sinus. The position of the leading edge of foods at swallow onset was significantly deeper in the pharynx with IPS than CPS ($P < 0.001$) (Table 2). The intra-rater reliability (ICC (1,1)) was 0.96 ($P < 0.001$) and the inter-rater reliability (ICC (2,1)) was 0.91 ($P < 0.001$).

Discussion

We found that IPS occurred not only in experimental situations, but also in daily eating with high intra- and inter-rater reliability. Age did not influence the occurrence of IPS. Several things were associated with the occurrence of an IPS. An IPS occurred more frequently with the mixed food than with liquid. Moreover, an IPS was more frequent with a deeper leading edge of the bolus. In particular, the leading edge of the mixed bolus was significantly lower at swallow onset in IPS than CPS, because the liquid phase of the mixed food was first to reach the valleculae and hypopharynx (transported by gravity) (Saitoh et al. 2007).

A lower bolus, especially in the hypopharynx without larynx closure, represents an increased risk of aspiration

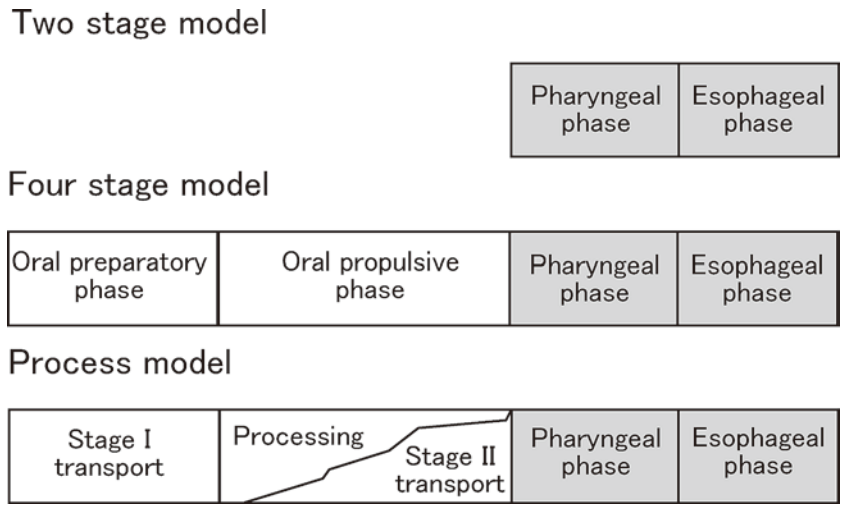

Fig. 3. Physiological model of swallowing.
Two stage, four stage and process model are shown.

(Saitoh et al. 2007). Therefore, we speculate that the mixed bolus was more likely to trigger an IPS as an airway protective mechanism. The occurrence of an IPS only in the first swallow of a multi-swallow trial was also consistent with airway protection. At the beginning of a trial there is a greater volume of food and liquid in the mouth. Some of this food may accidently be transported in a posterior direction without significant tongue movement.

The study of physiological processes is greatly aided by devising theoretical models that have both intuitive meaning and scientific validity. Theoretical models are important because they shape the way we think about physiological processes, and provide a framework for asking questions and formulating hypotheses that can be tested experimentally (Palmer and Hiiemae 1997). A two-stage model which consists of pharyngeal and esophageal phases fits the IPS (Fig. 3). In contrast to the 4-stage sequence model and the process model, an IPS has only 2 phases. The command swallow of liquids, explained by 4-stage model, is a volitional swallow, whereas a swallow that follows mastication, explained by the process model, arises in both in volitional and non-volitional situations. On the contrary, an IPS occurs in non-volitional situations only.

The definitions of reflex and volitional swallows are debated in the dysphagia community, as is the role of oral sensation in eliciting a pharyngeal swallow (Saitoh et al. 2007; Ertekin 2011; Humbert et al. 2012; Thexton et al. 2012). A current view is that rather than reflex and volitional being distinct categories, they represent ends of a continuum (Prochazka et al. 2000). The results presented here, as do those of German et al. (2009) and Humbert et al. (2012) support the idea that swallowing is more complex than a simple reflex or an entirely volitional behavior. Because IPS is not accompanied by bolus transport from the oral cavity, electromyography studies including submental muscles or tongue muscles during swallowing are needed to validate our findings (Ertekin et al. 2000, 2001). The present study demonstrates that an IPS is part of normal feeding, and that in general, swallows may contain components that fall at different places of the reflex-volitional axis.

Conflict of Interest

The authors declare no conflict of interest.

References

Dodds, W.J., Logemann, J.A. & Stewart, E.T. (1990) Radiologic assessment of abnormal oral and pharyngeal phases of swallowing. *AJR Am. J. Roentgenol.*, **154**, 965-974.

Ertekin, C. (2011) Voluntary versus spontaneous swallowing in man. *Dysphagia*, **26**, 183-192.

Ertekin, C., Aydogdu, I., Yüceyar, N., Kiylioglu, N., Tarlaci, S. & Uludag, B. (2000) Pathophysiological mechanisms of oropharyngeal dysphagia in amyotrophic lateral sclerosis. *Brain*, **123**, 125-140.

Ertekin, C., Kiylioglu, N., Tarlaci, S., Turman, A.B., Secil, Y. & Aydogdu, I. (2001) Voluntary and reflex influences on the initiation of swallowing reflex in man. *Dysphagia*, **16**, 40-47.

Feinberg, M.J. (1993) Radiographic techniques and interpretation of abnormal swallowing in adult and elderly patients. *Dysphagia*, **8**, 356-358.

German, R.Z., Crompton, A.W. & Thexton, A.J. (2009) Integration of the reflex pharyngeal swallow into rhythmic oral activity in a neurologically intact pig model. *J. Neurophysiol.*, **102**, 1017-1025.

Hiiemae, K.M. & Palmer, J.B. (1999) Food transport and bolus formation during complete feeding sequences on foods of different initial consistency. *Dysphagia*, **14**, 31-42.

Humbert, I.A., Lokhande, A., Christopherson, H., German, R. & Stone, A. (2012) Adaptation of swallowing hyo-laryngeal kinematics is distinct in oral vs. pharyngeal sensory processing. *J. Appl. Physiol.*, **112**, 1698-1705.

Linden, P., Tippett, D., Johnston, J., Siebens, A. & French, J. (1989) Bolus position at swallow onset in normal adults: preliminary observations. *Dysphagia*, **4**, 146-150.

Nishino, T. (1993) Swallowing as a protective reflex for the upper respiratory tract. *Anesthesiology*, **79**, 588-601.

Palmer, J.B. (1998) Bolus aggregation in the oropharynx does not depend on gravity. *Arch. Phys. Med. Rehabil.*, **79**, 691-696.

Palmer, J.B. & Hiiemae, K.M. (1997) Integration of oral and

pharyngeal bolus propulsion: a new model for the physiology of swallowing. *Jpn. J. Dysphagia Rehabil*., **1**, 15-24.

Palmer, J.B., Hiiemae, K.M. & Liu, J. (1997) Tongue-jaw linkages in human feeding: a preliminary videofluorographic study. *Arch. Oral Biol.*, **42**, 429-441.

Palmer, J.B., Rudin, N.J., Lara, G. & Crompton, A.W. (1992) Coordination of mastication and swallowing. *Dysphagia*, **7**, 187-200.

Pouderoux, P., Logemann, J.A. & Kahrilas, P.J. (1996) Pharyngeal swallowing elicited by fluid infusion: role of volition and vallecular containment. *Am. J. Physiol*., **270** (2 Pt 1), G347-354.

Prochazka, A., Clarac, F., Loeb, G.E., Rothwell, J.C. & Wolpaw, J.R. (2000) What do reflex and voluntary mean? Modern views on an ancient debate. *Exp. Brain Res*., **130**, 417-432.

Saitoh, E., Shibata, S., Matsuo, K., Baba, M., Fujii, W. & Palmer, J.B. (2007) Chewing and food consistency: effects on bolus transport and swallow initiation. *Dysphagia*, **22**, 100-107.

Shaker, R. (1995) Airway protective mechanisms: current concepts. *Dysphagia*, **10**, 216-227.

Shaker, R., Ren, J., Zamir, Z., Sarna, A., Liu, J. & Sui, Z. (1994) Effect of aging, position, and temperature on the threshold volume triggering pharyngeal swallows. *Gastroenterology*, **107**, 396-402.

Thexton, A.J., Crompton, A.W. & German, R.Z. (2007) Electromyographic activity during the reflex pharyngeal swallow in the pig: Doty and Bosma (1956) revisited. *J. Appl. Physiol.*, **102**, 587-600.

Thexton, A.J., Crompton, A.W. & German, R.Z. (2012) EMG activity in hyoid muscles during pig suckling. *J. Appl. Physiol.*, **112**, 1512-1519.