Initiation of reflex swallowing from the naso- and oropharynx

WILLIAM J. SINCLAIR
Faculty of Dentistry, University of Toronto, Toronto, Ontario, Canada

SINCLAIR, WILLIAM J. Initiation of reflex swallowing from the naso- and oropharynx. Am J Physiol 218(4): 956-960. 1970.—In 15 electrolytically decerebrated cats, the pharynx was exposed surgically from the ventral aspect and divided in the midline. The pharynx was mechanically stimulated with light pressure using a wooden applicator 4 mm in diameter. Swallowing was noted visually and later verified electromyographically. Areas eliciting swallows which occurred within 1-3 sec after application of the stimulus were recorded on a map of the pharynx. Observations were made on the effects of surface area stimulated, pressure, and movement patterns. The results showed that the posterior pillars were more reflexogenic, the posterior pharyngeal wall was slightly less, and the lateral pharyngeal wall was least reflexogenic. These areas extended into the nasopharynx. Larger diameter probes and heavier pressures appeared to be no more effective. Movement made mechanical stimulation more effective and showed directional sensitivity. Selective sectioning of the glossopharyngeal nerve (GPN) and the pharyngeal branch of the vagus nerve (PhX) demonstrated that the GPN is the prime afferent of the swallow reflex initiated from the pharynx and that the PhX plays a minor role.

reflexogenic sites; innervation of pharynx; adequate stimulus; pharyngeal reflex

REFLEX SWALLOWING IS A COMPLEX, unconditioned reflex. The intrinsic muscles of swallowing participate in a characteristic pattern (4) which can be differentiated from gagging, coughing, and vomiting (13). Reflex swallowing is initiated by mechanical or water stimulation of appropriate sites innervated by cranial nerves V, IX, and X. Mechanical stimulation of the lips (10), nasopharynx (12, 27), posterior pharyngeal wall (12, 16, 20, 27), soft palate (12, 16, 21, 27), fauicular pillars (12, 16, 20, 27), dorsum of the tongue (16, 21), pharyngeal surface of the epiglottis (12, 16, 21, 27), and the glossopiglottideal sinuses (16), has been shown to be an adequate stimulus. Water stimulation of the base of the tongue and glossopiglottideal sinuses (16), as well as the glottis and epiglottis (23), was also effective. Cranial nerves V (10, 12, 27), IX (3, 12, 21, 27), the superior laryngeal nerve (SLN) (3, 12, 21, 27), the recurrent branch of X (12, 22, 27), the accessory recurrent branch of X (22), and the main trunk of X (21) have been reported as afferents for the swallowing reflex.

Mechanical stimulation is the most effective stimulus in initiating reflex swallowing from the pharyngeal areas and water or hypotonic solutions from the larynx. Although the SLN is the primary afferent nerve for swallows initiated from the laryngeal portion of the airway, the role played by the GPN and the trigeminal nerve (TN) shows considerable species variability. In the cat, the GPN (12, 27) is described as the primary afferent of the swallow initiated from the pharynx while the TN has little (12) or no (27) importance. The paradox that electrical stimulation of the SLN elicits reflex deglutition more readily than does stimulation of the GPN remains unexplained (6). Some human clinical evidence (1, 7, 17) suggests that nerves other than the GPN may be involved in swallowing initiated from the pharynx. The pharyngeal areas initiating swallowing needed to be more carefully examined and the cranial nerve (or nerves) serving these areas more precisely identified. This study was designed to map the various pharyngeal areas in the cat as to the relative effectiveness of mechanical stimulation in eliciting swallowing. Some observations were made on the extent and depth of receptor fields, the significance of surface area stimulated, and movement patterns of the stimulus. The relative importance of the GPN and PhX as afferent nerves of the swallow was investigated by selective unilateral sectioning.

METHOD

In preparation for stimulation studies, 15 cats were electrolytically decerebrated. After initial anesthetization by intrathoracic administration of 4% sodium thiopental (Surital) solution (0.5 ml/kg), the animal was maintained on 4% Surital solution administered intravenously (0.1 ml as required) while a tracheotomy and craniotomy were performed. Coordinates for the decerebration (A5, ± 5 mm) were according to the atlas of Jasper and Ajmone-Marsan (11). Atropine sulfate was administered intramuscularly (2 mg/kg) to control oral and airway secretions. The pharynx was exposed from the ventral aspect, divided in the midline, and laid open with springs.

The posterior and lateral pharyngeal walls and the posterior pillars were stimulated by applying light pressure with a wooden applicator 4 mm in diameter. In each case the success or failure of a swallow to occur within 1-3 sec after the application of the stimulus was recorded on a diagram of the pharynx. Motor responses were noted visually and monitored electromyographically. Two unipolar electrodes of .0063-inch enamel-Nichrome wire (Driver Harris) were inserted by means of 26-gauge hypodermic needles into each unilateral mylohyoid, geniohyoid, cricothyroid, and thyroarytenoid muscle after a technique described by Inman. (The barbed wire electrodes were developed by Prosthetic
Devices Research Project (now Biomechanics Laboratory) at the University of California, Berkeley and San Francisco, during studies of human locomotion.) Electrode placement in the thyroarytenoid muscle was verified surgically at the end of the experiment. Muscle action potentials were displayed on a Tektronix four-channel cathode-ray oscilloscope and photographed. The mylohyoid muscle was also monitored on a loud speaker. Figure 1 shows typical recordings of swallowing, glottic closure, sniffing, and coughing. Swallowing was identified by sequential activity in the mylohyoid, geniohyoid, cricothyroid, and thyroarytenoid muscles. Glottic closure was indicated by a sudden burst of activity in the thyroarytenoid muscle only. Sniffing was shown by an increase in single-unit activity in the thyroarytenoid muscle. Coughing was characterized by synchronous activity in the cricothyroid and thyroarytenoid muscles and an absence of motor activity in the geniohyoid and mylohyoid muscles. An interval of 15 sec was allowed between successive stimulations to avoid receptor adaptation and central facilitation.

Observations were made on the effects of surface area stimulated by using wooden applicators 1, 2, 3, 5, and 6 mm in diameter. The effects of pressure increases of 1–3 oz were investigated using an adapted orthodontic Richmond strain gauge. The effects of movement patterns were observed using the 4-mm probe. After initial contact with the posterior pharyngeal wall, the 4-mm probe was slid towards the nasopharynx or larynx to see if there was any directional sensitivity. Finally, the SLN, GPN, and PhX were dissected free of attached fascia and bathed in light liquid paraffin oil. Each nerve was stimulated with a Grass square-wave stimulator isolated from ground in order to record typical reflex activity. In order, the SLN, GPN, and PhX were sequentially sectioned unilaterally. In each instance, the effect on reflex swallowing initiated by mechanical stimulation of the ipsilateral pharyngeal wall was observed.

RESULTS

The results are summarized in Fig. 2. The data show that the most reflexogenic site was located lateral to the posterior pharyngeal wall in an area corresponding to the posterior pillars. In a total of 131 stimulations of this area, 87% elicited reflex swallowing. The posterior pharyngeal wall was slightly less effective. In a total of 178 stimulations, 80% produced swallowing. Note that these two areas extended into the nasopharynx for a short distance (1–2 mm). The lateral pharyngeal wall was least effective; only 56% were successful in 92 stimulations. Observations indicated that only sporadic swallows could be elicited from the peritonsillar area and pharyngeal mucosa located close to the vocal cords. The base of the tongue, oro- and nasopharyngeal surface of the soft palate (apart from that area included in Fig. 2), and the vocal cords did not give rise to swallowing. Mechanical stimulation of deeper nasopharyngeal tissue resulted in respiratory movements similar to sniffing. Me-

![Figure 1](http://ajplegacy.physiology.org/)

**Fig. 1.** A: typical electromyographic recordings of a swallow initiated by mechanical stimulation of posterior pharyngeal wall with a probe 4 mm in diameter. B: a recording of glottic closure on mechanical stimulation of vocal cords. C: a recording of respiratory activity similar to sniffing on mechanical stimulation of deep nasopharyngeal mucosa. D: a recording of a cough due to mechanical stimulation of vocal cords. Horizontal calibration represents 0.5 sec, and vertical calibration 500 μV. Mylohyoid = mh; geniohyoid = gh; cricothyroid = ct; and thyroarytenoid muscles = ta.
mechanical stimulation with a stimulator 4 mm in diameter appeared to be more effective than an applicator of smaller diameter; increasing the surface area of the probe to 5 or 6 mm did not make the probe more effective. Increasing the pressure applied by the 4-mm probe from light pressure to 1, 2, or 3 oz appeared to elicit swallows less readily and sometimes resulted in a cough. In contrast, movement patterns did enhance the response. When initial contact of the posterior pharyngeal wall failed to elicit a swallow, sliding the 4-mm probe toward the larynx would occasionally be effective. However, swallows would occur more readily if the probe was slid toward the nasopharynx. By continuing this movement pattern, a series of 4–5 swallows could be elicited.

Figure 3 shows typical reflex activity. The PhX was characterized by an initial swallow of short latency (1–2 sec) sometimes followed by sequential swallows. The SLN was characterized by an initial swallow of longer latency (3–4 sec) followed by sequential swallows. The GPN elicited swallows with greater difficulty; stimulation was often associated with limb and increased respiratory movement. A swallow often occurred when the stimulation was terminated.

In 12 decerebrate cats studied, section of the SLN had no effect on swallowing initiated from the ipsilateral pharyngeal wall when mechanically stimulated. Selective section of the GPN abolished reflex swallowing completely in five animals and partially in four animals. In these four animals, section of the PhX abolished the swallowing reflex. In contrast, section of the PhX abolished reflex swallowing completely in only two animals. Swallows in all instances could still be elicited from the intact side of the pharynx. It was difficult to describe any specific area innervated by the GPN or the PhX because of their apparent sensory overlap. However, sectioning of the GPN had less effect on swallowing elicited from the dorsolateral aspect of the nasopharynx.

DISCUSSION

The reflexogenic areas mapped in this study amplify previous findings (12, 16, 20, 21, 27). The surgical preparation allowed for closer inspection of the areas stimulated and for the electromyographic identification of the response elicited. The boundaries defined in this study permit comparison with the fields of single sensory units of the GPN and PhX currently being studied. In this way, the relative role of the GPN and PhX in reflex swallowing can be assessed. The localization of tactile units would be expected to correspond to the areas mapped in this study.

The protective role of the swallow in sealing off the nasopharyngeal isthmus to prevent the influx of material during swallowing has been described. Frenckner (9), from X-ray cinematographic studies, showed that the soft palate in the human is raised against the nasopharyngeal tissue before the base of the tongue contacts the posterior pharyngeal wall. Negus (18) and Bosma (2) also support this view. Electromyographic findings of Doty and Bosma (4) indicate that the palatopharyngeus muscle participates in the lead complex. The nasopharyngeal sites mapped in this study would correspond to areas that would be stimulated initially when the soft palate is raised against the posterior pharyngeal wall. Since careful stimulation of the soft palate and the base of the tongue did not produce reflex swallowing, their contact against contiguous structures seems essential to elicit swallowing. Movement of the stimulus toward the nasopharynx was more effective than similar movements toward the larynx. The motion of the tongue during deglutition would facilitate swallowing. Clearly swallowing, apart from its classical visceral function, also plays an important protective role in guarding both the nasal and laryngeal portions of the airway.

Some evidence for spatial summation is shown by the greater effectiveness of the larger sized probes. Storey (24) reported that the frequency and adaptation rates for water and tactile units in the larynx were similar. Doty (3) showed that the optimum frequency of stimulation of 30 cycles/sec for swallow initiated by electrical stimulation of the SLN was independent of the pattern of the stimulus. Observations reported here would suggest that the surface area stimulated and the sequence of receptor stimulation may hold the key for explaining the mechanism of eliciting reflex swallowing. There is no evidence to suggest that the "pluri-potential" laryngeal receptors described by Storey (24) exist in the pharynx of the cat. Water dropped into the pharynx would not elicit reflex swallowing unless it was allowed to contact the vocal cords or epiglottis. Although mechanical stimulation of the pharynx failed to produce coughing, gag-
SWALLOWING

PhX

A

mh
gh
cf

SLN

B

mh
gh
cf

2 SECONDS

2 SECONDS

Fig. 3. A: typical recorded swallow activity due to electrical stimulation of PhX at 30 cycles/sec and 0.4 v. Note that latency to onset of first swallow is 0.3 sec; interval to onset of second swallow is 0.4 sec. Continued stimulation failed to produce further swallows. B: typical recorded swallow activity due to electrical stimulation of the SLN at 30 cycles/sec and 0.2 v. Note that latency to onset of first swallow is 2.5 sec; intervals to onset of successive swallows are 2.2 and 1.1 sec. Two seconds of tracing have been removed before first and second swallow. Arrow indicates onset of stimulation. Horizontal calibration represents 0.5 sec and vertical calibration 500 C.V. Mylohyoid = mh; geniohyoid = gh; cricothyroid = ct; and thyroarytenoid muscles = ta.

The author is indebted to Dr. A. T. Storey for his valued counsel and encouragement.

This study was submitted in partial fulfilment of the requirements for the Diploma Course in Orthodontics and was supported in part by National Research Council Grant DA-147.

Received for publication 9 October 1969.

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