Review

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Reflex influences on oropharyngeal swallowing

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Abstract

Swallowing is a complex sensorimotor behaviour involving the coordinated and reflex contraction and inhibition of the musculature located in and around the mouth, larynx, pharynx and esophagus. Voluntary swallowing is under the the control of the cerebral cortex and other subcortical structures, but the main locations are the nucleus tractus solitarius and nucleus ambiguus, and their neural network of central pattern generator. In spite of these central controls, there are some intrinsic reflex actions between three phases of swallowing. These kind of reflexes were emphasized in this review.

Keywords: central pattern generator; larynx; pharynx; protective reflexes; swallowing

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Introduction

It is well known since Magendie in 1825 wrote (cited from Miller, 1982)[1] that swallowing is subdivided into three phases; first one is the oral phase, mostly under voluntary control, second is the pharyngeal phase, a kind of "swallowing reflex"; and third is esophageal phase, involuntary and autonomic. However, oral and pharyngeal phases are firmly related to each other toward the end of oral phases. Therefore, they can be called "oropharyngeal swallowing" or "bucco-pharyngeal swallowing".[2–4] It has been recently documented that the cerebral cortex could be involved with the oropharyngeal swallowing as demonstrated by studies using neuroimaging techniques in humans. Animal studies have also shown that that there is a network in the brainstem called "central pattern generator" (CPG) where swallowing could be arranged according to the needs.

In daily life, we swallow more than 1000 times; however, this number changes according to different reports.[5–10] All the swallowing movements during daily life can not to be initiated or triggered by the cerebral cortex, some of them may occur without cortical influences. According to this view, swallows can be classified as two types. One of them is the "voluntary induced swallows" which are very frequent during meal times. While other times, including sleep, we are often unaware of our swallowing. These could be called "spontaneous" or "reflexive" swallows.[11] Probably, a third type of swallowing movement may also exist during some stressful emotional conditions. Spontaneous and emotional swallows are certainly "saliva swallows" and mostly in reflexive nature. It may be speculated that there may be some neural control from limbic and/or extrapyramidal system in saliva swallows.[4,9,12] As a matter of fact, the reflexive swallows could also describe some clinical conditions. A normal human fetus can swallow by the 12th gestational week, before the cortical and subcortical structures have developed.[2,3] It has also been reported that swallowing is still possible in the human anencephalic fetus. Thexton & Crompton 1998; Jean 2001; Miller et al 2003; Peleg and Goldman 1978; Pritchard 1965).[2,3,13–15] Similarly, pharyngeal phase of swallowing without oral phase may also be considered as a reflexive swallow[16] in both human[17,18] and animals.[19,20] Furthermore, the activation of the pharyngeal phase of swallowing without subsequent activation of the esophageal phase is reported as a common finding in humans especially during dry swallowing or saliva swallowing throughout daily life and it is called the failed swallow.[16] In humans, failed swallows occur 3-4% of the time during wet swallows and 29-38% of the time during dry swallows.[21,22]

During voluntary induced swallowing, the cascade of the sequential muscle activation does not essentially change from mouth to esophagus. This is one of the lines for the existence of CPG in human swallowing.[23] This may mean that after the triggering of the oro-pharyngeal swallowing either in the oral cavity for voluntary swallow or in the pharyngeal spaces for reflexive swallow, orderly and sequentially muscle activation of more than 33 muscle pairs invariably reaches from lip through the esophagus. If we mention again, this sequential muscle activation is a function of the CPG of the swallowing. This pattern of oropharyngeal activation has been known since more than fifty years ago in mammals.[1,19,20,24] The overall pattern of electromyographic activity during reflexive swallowing represents the response of the brainstem pattern generator, a purely peripheral sensory input, independent from any descending cerebral influence.[20] However, during the swallowing in intact human and in high level animal organisms, it is possible that descending cortical drives and sensory inputs from oropharynx can converge in order to provide a safe and satisfactory swallow. However, the CPG governs not only the timing of motor response of each phase of swallowing, but also controls the timing between the phases of swallowing[16] according to the cortical evaluation and the present condition of sensory feedback from the oropharynx. The experimental insufficiency of sensory coding[25–28] would produce an uncertain evaluation of the human central nervous system. The main role of the oropharyngeal mucosal receptors is to contribute to the initiation of swallowing, but when swallowing is triggered cortically or reflexively the pattern and sequential activity of the swallow is not essentially changed. Thus, the stereotypic movements of the oropharyngeal swallowing are also controlled by the CPG of the brainstem like in experimental animal studies.[3,4,29] The interneurons at the nucleus tractus solitarius (NTS) (premotor neurons) situated at the medulla oblongata are rather motor generator neurons involved in the triggering, shaping and timing of the sequential and rhythmic swallowing pattern. NTS receives not only peripheral sensory inputs, but also cortical and subcortical descending drives. On the other hand, premotor neurons in and around NTS contain the "switching neurons" which distrubute the swallowing output to the various motoneuron pools properly.[3,29] Before and during swallowing, the sensory inputs from the oropharynx to the somatosensory cortical areas may be expected in addition to that of the medullary swallowing network for precise information from both the bolus and the position of the oropharynx.[30–32] Therefore, the sensory input appears to be vital to the oropharyngeal swallowing. Sensory inputs from the oral cavity, especially tonsillar pillar, base of the tongue and oropharyngeal mucosa have been proposed to be important for the triggering of swallows.[1,3,27,28,32–36] Unfortunately, neither only cerebral cortex nor oropharyngeal input alone have not systematically produced or inhibited human swallowing completely. Important convergence from both motor and sensory inputs on the brainstem swallowing network of CPG must be necessary for the human voluntary swallows. The initiation or triggering of swallowing is probably more complex in human and may be dependent on the type of bolus; single or consecutive swallows, voluntary or reflex induced swallowing. It has been clearly demonstrated that in human the solid foods and liquids reaches the valleculae in advance of swallowing.[37,38] The initiation of swallow can be expected from the posterior part of oral cavity to the hypopharynx depending on the different kind of bolus. Recently in consecutive swallow and/or drinking, pharyngeal bolus accumulation of masticated or drinking material has been identified in the valleculae of pharynx.[39–43] Thus, the hypopharynx may be a crucial trigger point in the elicitation of the pharyngeal swallow.[43]

Beyond the cortical/subcortical drives and sensory input from the oropharynx, the sequential swallows can be controlled mostly by the CPG generating neurons in and around NTS firing a sequential or rhytmic pattern that parallel to the sequential motor pattern of the oropharyngeal swallowing.[3,29,44] However, we do not know about detail of CPG especially in human. During oropharyngeal swallowing, there are two main purposes for human. One of them is that the bolus should be directed to right way by entering into the esophagus. Second main purpose is the protection of the airway against any escape of the bolus or part of it. It has been shown that apart from the CPG generator of swallowing, there are some protective reflexes for swallowing. They do not always take place in the sequential muscle activation of CPG; but, they are ready for any kind of risk of aspiration of oropharyngeaal swallowing. It is well known that the cough reflex and gag reflex are some kind of protective reflexes. However, there are some other reflexes that could be observed during studies of oropharyngeal swallowing and they may be important for the security of airway and the descending direction of the bolus into the esophagus.[45] These kind of protective reflexes can be clearly studied by the electrophysiological methods. During pharyngeal phase of swallowing, larynx is closed by the contraction of the adductor muscles of the vocal cord. The thyroaritenoid (TA) muscle of the vocal cord is a laryngeal adductor and its contraction causes laryngeal closure during pulling up larynx and this results in very dense EMG activity of the TA muscle. In the mean time, cricopharyngeal (CP) sphincter is relaxed, opened and closed accordingly during swallowing.[45,46] Therefore, the refined-protective reflexes could be searched by the needle EMG inserted into the TA and/or CP sphincter muscles. For TA muscle, there can be a protective reflex just before the closure of TA by a very dense EMG activity during water swallowing. The reflex activity just before the swallowing is a protective reflex and may prevent the escape of premature pieces of bolus from intraoral to laryngo-pharyngeal spaces. Thus CPG plus oropharyngeal protective reflexes are synergically interacted for the safe swallowing.[45]

Previously, the laryngeal closure response to afferent stimulation was studied by electrical stimulation of the internal branch of the superior laryngeal nerve (SLN) in both animals and humans. These protective reflexes were induced by the stimulation of the sensory afferents of SLN.[47–49] However, the repetitive stimulation of the SLN could also produce "fictive swallowing" in experimental animals, but in human SLN stimulation could never evoke any kind of swallowing patterns.[49] It has been demonstrated that when the swallow is initiated, a change in sensitivity of laryngeal afferents may have occurred because of laryngeal mechanoreceptor adaptation to continuous stimulation ongoing in the pharyngeal and laryngeal regions.[50]

In conventional EMG, CP-sphincter has continuous tonic activity,[23,46] but during swallowing the tonic EMG activity of CP-sphincter clearly ceases and sphincter opens with a duration of 400-600 msec for a single 3-5 ml water swallow. What is important is that when the sphincter opens two bursts of EMG activity appear just before and after the EMG pause. Earlier burst is called foreburst and occurs just before the EMG-pause. Second late burst is called rebound burst and appears after the CP-EMG pause.[23,46] Rebound burst activity is always observed with each swallow, therefore it should belong to the sequential muscle activation of CPG. But foreburst can not be found in each normal subject, and therefore may be related with protective reflexes. If we make intraoral topical anesthesia, the foreburst disappears during anesthesia, rebound burst does not change significantly. Therefore, the foreburst of CP-sphincter and earlier burst of TA of the vocal cord should be some kind of protective reflexes and probably initiated from the intraoral receptors.[45,51,52] The laryngeal and glottic closure (vocal fold) and the upper esophageal sphincter have been investigated by videofluoroscopic manometric and endoscopic methods.[53–56] As mentioned, the laryngeal glottic closure was found in a close temporal relation with the onset of UES opening.[45,57] However, there is some variability in this time relation[57–60] which is associated with the onset and duration of the UES opening and/or glottic closure. However, in this variability in airway closure and UES opening, there is even fine tuned mechanisms between the basic activity of TA muscle and the upper esophageal CP sphincter. Celik Gokyigit et al.[61] demonstrated that three kind of swallowing patterns appeared between two muscles electromyographically. In the first pattern TA muscle EMG excitation is later than the onset of upper esophageal sphincter opening more than 50 msec. This kind of swallow may cause laryngeal penetration especially in neurogenic dysphagia. In the second pattern of swallow, EMG excitation basic activity of TA muscle overlaps with the CP-EMG pause. In the third pattern; the onset of EMG closure of TA muscle is earlier than CP EMG pause more than 50 msec. Third pattern is obviously much more safe because of complete closure of the airway before the bolus reached to the upper esophageal CP sphincter. Indeed, duration of the TA basic EMG activity increases and preceedes or overlaps with CP EMG pause, with an increase of bolus volumes.[61] These observations in normal human subjects are not purely reflexive movements, but the contribution of the cerebral cortex and CPG of the brainstem can not be elucidated.

We did not mention other reflex mechanisms related with respiration and deglutition in this scope of review. However, swallowing mechanism may also modulate both respiratory control and laryngeal responses to sensory stimuli following swallowing act.[49,50,62]

References

1. Miller AJ. Deglutition. Physiol Rev 1982;62:129–84.
2. Thexton AJ, Crompton AW. The control of swallowing. In: Linden RWA, ed. Frontiers of Oral Biology. Basel: Karger; 1998; p. 168–222.
3. Jean A. Brainstem control of swallowing: neuronal network and cellular mechanisms. Physiol Rev 2001;81:929–69.
4. Ertekin C, Aydogdu I. Neurophysiology of swallowing. Clin Neurophysiol 2003;114:2226–44.
5. Lear CSC, Flanagan JBJ, Moorrees CFA. The frequency of deglutition in man. Arch Oral Biol 1965;10:83–99.
6. Calloway S, Fonagy D, Pounder R. Frequency of swallowing in duodenal ulceration and hiatus hernia. Br Med J 1982;285:23–4.
7. Kapila YV, Doddo WJ, Helm JF, Hogan WJ. Relationship between swallow rate and salivary flow. Dig Dis Sci 1984;29:528–33.
8. Lagerlöf F, Dawes C. The volume of saliva in the mouth before and after swallowing. J Dent Res 1984;63:618–21.
9. Pehlivan M, Yüceyar N, Ertekin C, Celebi G, Ertaş M, Kalayci T, Aydoğdu I. An electronic device measuring the frequency of spontaneous swallowing: digital phagometer. Dysphagia 1996;11:259–64.
10. Rudney JD, Larson CJ. The prediction of saliva swallowing frequency in humans from estimates of salivary flow rate and the volume of saliva swallowed. Arch Oral Biol 1995;40:507–12.

11. Ertekin C. Voluntary versus spontaneous swallowing in man. Dysphagia 2011;26:183–92.
12. Ertekin C, Kiylioglu N, Tarlaci S, Turman AB, Secil Y, Aydogdu I. Voluntary and reflex influences on the initiation of swallowing reflex in man. Dysphagia 2001;16:40–7.
13. Miller JL, Sonies BC, Macedonia C. Emergence of oropharyngeal, laryngeal and swallowing activity in the developing fetal upper aerodigestive tract: an ultrasound evaluation. Early Hum Dev 2003; 71:61–87.
14. Poleg D, Goldman JA. Fetal deglutition: a study of the anencephalic fetus. Eur J Obstet Gynecol Reprod Biol 1978;8:133–6.
15. Pritchard JA. Deglutition by normal and anencephalic fetus. J Obstet Gynecol 1965; 25:289–97.
16. Martin, RE Neuroplasticity and swallowing. Dysphagia 2009;24: 218–29.
17. Nishino T. Swallowing as a protective reflex for the upper respiratory tract. Anesthesiology 1993;79:588–601.
18. Shaker R, Ren J, Zamir Z, Sarna S, Liv J, Sui Z. Effect of aging, position and temperature on the threshold volume triggering pharyngeal swallows. 1994;107:396–402.
19. Doty RW, Bosma JF. An electromyographic analysis of reflex deglutition. J Neurophysiol 1956;19:44–60.
20. Thexton AJ, Crompton AW, German RZ. Electromyographic activity during the reflex pharyngeal swallow in the pig: Doty and Bosma (1956) revisited. J Appl Physiol 2007;102:587–600.
21. Dodds WJ, Hogan WJ, Reid DP, Stewart ET, Arndorfer RC. A comparison between primary esophageal peristalsis following wet and dry swallows. J Appl Physiol 1973;35:851–7.
22. Hollis JB, Castell DO. Effect of dry swallows and wet swallows of different volumes on esophageal peristalsis. J Appl Physiol 1975;38:1161–4.
23. Ertekin C, Aydogdu I. Electromyography of human cricopharyngeal muscle of the upper esophageal sphincter. Muscle Nerve 2002; 26:729–39.
24. Miller AJ. The neurobiology of swallowing and dysphagia. Dev Disabil Res Rev 2008;14:77–86.
25. Ertekin C, Kıylıoğlu N, Tarlacı S, Keskin A, Aydoğdu I. Effect of mucosal anaesthesia on oropharyngeal swallowing. Neurogastroenterol Motil 2000;12:567–72.
26. Ali GN, Laundl TM, Wallace KL, Shaw DW, deCarle DJ, Cook IJ. Influence of mucosal receptors on deglutive regulation of pharyngeal and upper esophageal sphincter function. Am J Physiol 1994;267:G644–9.
27. Mansson I, Sandberg N. Effect of surface anesthesia on deglutition in man. Laryngoscope 1974;84:427–37.
28. Mansson I, Sandberg N. Salivary stimulus and swallowing reflex in man. Acta Otolaryngol 1975;79:445–50.
29. Jean A, Dallaporta M. Electrophysiologic characterization of the swallowing pattern generator in the brainstem. GI Motility Online 2006; DOI: http://dx.doi.org/10.1038/gimo9
30. Jean A, Car A, Roman C. Comparison of activity in pontine versus medullary neurons during swallowing. Exp Brain Res 1975;22:211–20.
31. Jafari S, Prince RA, Kim DY, Paydarfar D. Sensory regulation of swallowing and airway protection: a role for the internal superior laryngeal nerve in humans. J Physiol 2003;550:287–304.
32. Lowell SY, Poletto CJ, Bethany RKC, Reynolds RC, Simonyan K, Ludlow CL. Sensory stimulation activates both motor and sensory components of the swallowing system. Neuroimage 2008;42:285–95.
33. Miller AJ. The neuroscientific principles of swallowing and dysphagia. San Diego (CA): Singular Publication Group; 1999.
34. Jean A. Brainstem organisation of the swallowing network. Brain Behav Evol 1984;25:109–16.
35. Jean A. Control of the central swallowing program by inputs from the principal receptors. A review. J Auton Nerv Syst 1986;10:225–33.
36. Logemann JA. Evaluation and treatment of swallowing disorders. 2nd ed. Austin (TX): Pro Ed; 1998.
37. Palmer JB, Rudin NJ, Lara G, Crompton AW. Coordination of mastication and swallowing. Dysphagia 1992;7:187–200.
38. Pouderoux P, Logemann JA, Kahrilas PJ. Pharyngeal swallowing elivcited by fluid infusion: role of volition and vallecular containment. Am J Physiol 1996;270:G347–54.
39. Dua KS, Ren J, Bardon E, Xie P, Shaker R. Coordination of deglutive glottal function and pharyngeal bolus transit during normal eating. Gastroenterology 1997;112:73–83.
40. Hiiemae KM, Palmer JB. Food transport and bolus formation during complete feeding sequences on foods of different initial consistencies. Dysphagia 1999;14:31–42.
41. Chi-Fishman G, Sonies BC. Motor strategy in rapid sequential swallowing: New insights. J Speech Lang Hear Res 2000;43:1481–92.
42. Daniels SK, Foundas AL. Swallowing physiology of sequential straw drinking. Dysphagia 2001;16:176–82.
43. Daniels SK, Grey D, Hadskey LD, Legendre C, Priestly DH, Rosenbek JC, Foundas AC. Mechanism of sequential swallowing during straw drinking in healty young and older adults. J Speech Lang Hear Res 2004;47:33–45.
44. Kessler JP, Jean A. Identification of medullary swallowing regions in the rat. Exp Brain Res. 1985;57:256–63.
45. Ertekin C, Celik M, Seçil Y, Tarlaci S, Kiylioğlu N, Aydoğdu I. The electromyographic behaviour of the thyroarytenoid muscle during swallowing. J Clin Gastroenterol 2000;30:274–80.
46. Ertekin C, Pehlivan M, Aydoğdu I, Ertaş M, Uludağ B, Celebi G, Colakoğlu Z, Sağduyu A, Yüceyar N. An electrophysiological investigation of deglutition in man. Muscle Nerve1995;18:1177–86.
47. Ludlow CL, Vanpelt F, Koda J. Characteristics of late responses to superior laryngeal nerve stimulation in humans. Ann Otol Rhinol Laryngol 1992;101:127–34.
48. Sasaki CT, Suzuki M. Laryngeal reflexes in cat, dog and man. Arch Otolaryngol 1976;102:400–2.
49. Barkmeier JM, Bielamowicz S, Takeda N, Ludlow L. Modulation of laryngeal responses to superior laryngeal nerve stimulation by volutional swallowing in awake humans. J Neurophysiol 2000;83:1264–72.
50. Esaki H, Toshiro U, Selh T, Shin T. Characteristics of laryngeal receptors analysed by presynaptic recording from the cat medulla oblongata. Auris Nasus Larynx 1997;24:73–93.
51. Celik M, Alkan Z, Ercan I, Ertaşoğlu H, Alkım C, Erdem L Turgut S, Ertekin C. Cricopharyngeal muscle electromyography in laryngopharyngeal reflux. Laryngoscope 2005;115:138–48.
52. Andreatta RD, Mann EA, Poletto CJ, Ludlow CL. Mucosal afferents mediate laryngeal adductor responses in the cat. J Appl Physiol 2002;93:1622–9.
53. Shaker R, Dodds WJ, Dantas RO, Hogan WJ, Arndorfer RC. Coordination of deglutitive glottic closure with oropharyngeal swallowing. Gastroenterology 1990;98:1478–84.

54. Martin BJW, Logemann JA, Shaker R, Dodds WJ. Coordination between respiration and swallowing: respiratory phase relationship and temporal integration. J Appl Physiol 1994;76:714–24.
55. Curtis DJ, Cruess DF, Dachman AH, Maso E. Timing in the normal pharyngeal swallow: prospective selection and evaluation of 18 normal asymptomatic patients investigation. Invest Radiol 1984; 19:523–9.
56. McConnell FM, Cerenko D, Jackson RT, Guffin Tn Jr. Timing of major event of pharyngeal swallowing. Arch Otolaryngol Head Neck Surg 1988;114:1413–8.
57. Kendall KA, McKenzie S, Leonard RJ, Gonçalves MI, Walker A. Timing events in normal swallowing: a videofluoroscopic study. Dysphagia 2000;15:74–83.
58. Kendall KA. Oropharyngeal swallowing variability. Laryngoscope 2002;112:547–51.
59. Kendall KA, Leonard RJ, McKenzie SW. Sequence variability during hypopharyngeal bolus transit. Dysphagia 2003;18:85–91.
60. Ohmae Y, LogemannJA, Kaiser P, Hansen DG, Kahrilas PJ. Timing of glottic closure during normal swallow. Head Neck 1995;17:394–402.
61. Celik Gokyigit M, Kuloglu Pazarci N, Ercan I, Seker S, Turgut S, Ertekin C. Identification of distinct swallowing patterns for different bolus volumes. Clin Neurophysiol 2009;120:1750–4.
62. Dozier TS, Brodsky MB, Michel Y, Walters Jr BC, Martin-Harris B. Coordination of swallowing and respiration in normal sequential cup swallows. Laryngoscope 2006;116:489–93.

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