PHYSIOLOGY OF SWALLOWING AND EATING DISORDERS

Renu Rajguru, Monalisa Jati

Swallowing is a complex human activity that depends on the precise coordination of the actions of the oral cavity, pharynx, larynx, and oesophagus, under the control of an integrated neural network. Understanding the physiology and neural regulation of swallowing is crucial for comprehending the fundamental mechanisms that govern this process and for appreciating its inherent complexity. Swallowing is mediated by coordinated interactions between cortical, subcortical, and brainstem structures, which integrate sensory input and generate organised motor output to ensure efficient bolus transport and airway protection. The swallowing sequence is traditionally divided into distinct stages, each characterised by specific food management behaviours. To describe these events, commonly used models of drinking and eating provide complementary frameworks for understanding normal swallowing function and for identifying abnormalities relevant to experimental investigation and clinical management.

Keywords: *Oral cavity, pharynx, larynx, oesophagus, neural regulation*

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Introduction

Swallowing is a dynamic, multi-stage neuromuscular process that involves the coordinated movement of food or liquid from the oral cavity to the stomach, requiring precise synchrony among sensory inputs, cortical and brainstem integration, and motor execution (Logemann, 1998; Jean, 2001; Miller, 2008; Michou & Hamdy, 2009; Labeit et al., 2019). Several models have been proposed to explain this complex process, with different perspectives depending on the type of food, clinical need, and the level of physiologic detail required.

Overview of the Swallowing Models

Traditional physiological descriptions began with the **three-phase sequential model**, introduced by Magendie in 1825, which divides swallowing into oral, pharyngeal, and oesophageal phases based on the location of the bolus (Miller, 1982; Ertekin & Aydogdu, 2023). As clinical instrumentation improved, particularly with the development of video-fluoroscopy, the oral phase was subdivided into preparatory and propulsive stages, resulting in the widely used four-stage model (Figure 1). This remains the standard framework in dysphagia evaluation, especially for liquid swallowing during clinical trials.

However, real-life feeding does not always follow a linear sequence. Mastication, bolus formation, and partial bolus transport occur simultaneously while eating solids. This led Palmer and colleagues to describe the process model (Figure 1), which provides a more accurate representation of solid-food swallowing as a dynamic, overlapping process (Palmer et al., 1992; Matsuo & Fujishima, 2020). Additionally, studies on spontaneous and infant swallowing identified a two-stage model (Figure 1) pharyngeal and oesophageal only representing reflexive swallowing in the absence of an active oral preparatory phase (Kagaya, 2015).

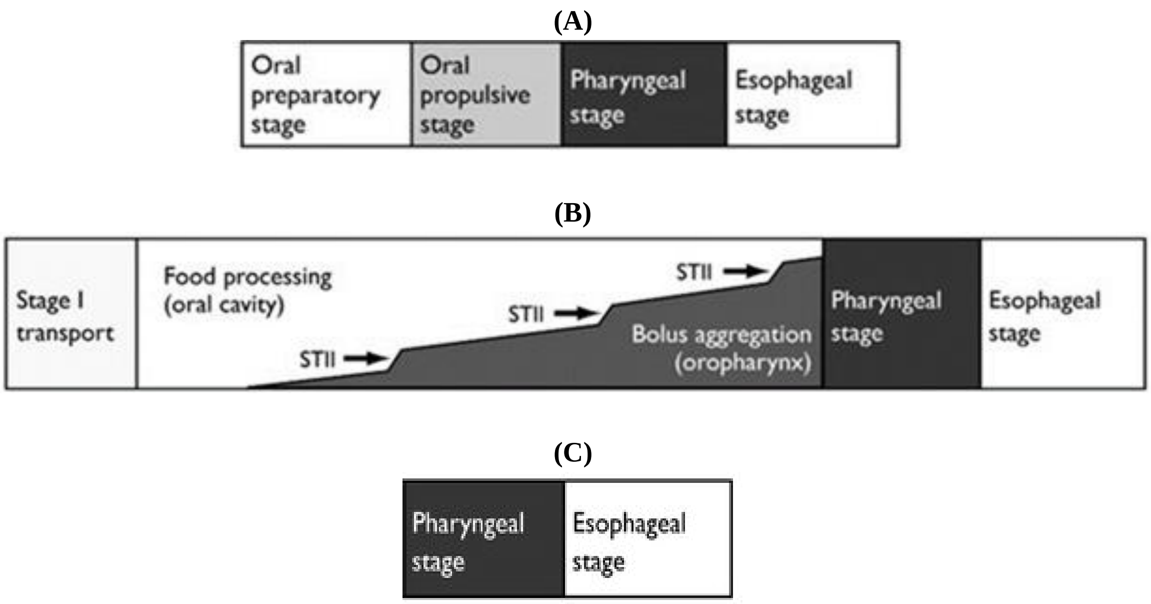


Figure 1. Swallowing Models

(A) Four-stage Model: Liquid swallowing follows a predominantly sequential four-stage pattern.

(B) Process Model: In solid food intake, the timing of food processing and stage II transport (STII; with aggregation in the oropharynx) can overlap substantially (Matsuo & Fujishima, 2020).

(C) Two-Stage Model: Reflexive Swallowing Without an Active Oral Preparatory Phase (Kagaya et al., 2015).

More recently, neurophysiological models have gained importance, emphasising the central pattern generator in the brainstem, cortical modulation, cranial nerve pathways, sensory feedback, and airway protection strategies. This framework provides a better understanding of variability in swallowing, adaptive responses following surgery, and dysphagia resulting from neurological or structural disorders.

Stages of Swallowing

Swallowing is a continuous process traditionally divided into oral preparatory, oral, pharyngeal, and oesophageal phases (Fyke & Code,1955; Mandelstam & Lieber, 1970; Miller, 1972; Sessle & Hannan, 1976; Logemann, 1998). The oral preparatory and oral phases involve voluntary chewing, bolus formation, and propulsion, while the pharyngeal and oesophageal phases occur automatically to protect the airway and move the bolus to the stomach (Ingervall, 1978; Larson & Sutton, 1978). Current evidence shows the pharyngeal phase is not purely reflexive but a modifiable pre-programmed motor sequence influenced by bolus characteristics and sensory input (Logemann, 2006; Zainaee et al., 2025).

Oral Preparatory Stage

The oral preparatory stage marks the beginning of swallowing and is characterised by voluntary, highly coordinated neuromuscular activity. Once food or liquid enters the mouth, the primary goal of this stage is to prepare a cohesive bolus that is safe for transport into the pharynx (Figure 2) (Miller, 1982; Logemann, 1998). Liquids are generally held on the anterior floor of the mouth or on the tongue surface, supported by the hard palate and enclosed within the upper dental arch. A firm seal is created by contraction of the orbicularis oris, preventing anterior leakage, while the jaw is stabilised by coordinated activation of the masticatory muscles. Simultaneously, contraction of the buccinator muscles maintains cheek tension against the teeth, preventing food materials from collecting in the lateral sulci (Matsuo & Palmer, 2008).

In contrast to liquid ingestion, the consumption of solid food requires a more intricate and highly coordinated sequence of events. Rhythmic vertical and rotary mandibular movements enable the teeth to break food into smaller particles, while the tongue diligently positions and redistributes the food particles onto the occlusal surfaces to optimise mastication (Steele et al., 2019). Throughout this process, saliva plays a critical and multifaceted role. It lubricates the oral structures and food particles, binds fragmented materials into a cohesive bolus, and facilitates efficient bolus manipulation and formation. Acting as a solvent for tastants, saliva supports taste perception and provides essential sensory feedback regarding bolus quality. Its enzymatic components further contribute by initiating early digestion, particularly the breakdown of carbohydrates (Cichero, 2018). Beyond bolus preparation, saliva is vital for maintaining oral health through dental and mucosal protection, regulation of oral pH, and antimicrobial defence.

Also, adequate salivary volume is essential for successful swallowing, as reduced salivary flow compromises bolus cohesion and can render even a dry swallow difficult. Ultimately, the coordinated actions of the tongue, teeth, cheeks, jaw, and saliva transform the solid food into a bolus of appropriate texture and consistency, ensuring safe and efficient swallowing. During this oral preparatory phase, the soft palate rests in gentle contact with the posterior tongue, forming a temporary barrier that intentionally separates the oral cavity from the oropharynx. This intentional separation prevents premature spillage of food material into the pharynx and protects the airway before the swallow is initiated (Logemann, 1998).

As the larynx and pharynx remain inactive at this stage, the airway stays open and nasal breathing continues uninterrupted (Matsuo & Palmer, 2008). Continuous sensory feedback related to taste, texture, temperature, and pressure informs the central nervous system about bolus readiness, ensuring that the transition to the subsequent stage of swallowing occurs only when the bolus meets the physiological criteria for safe transport.

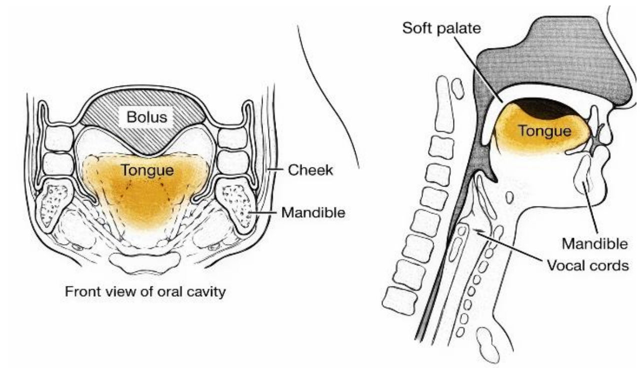


Figure 2. The anterior and lateral views of tongue position in holding bolus immediately before initiating oral stage of swallow (Logemann, 2015).

Oral Propulsive Stage

The oral propulsive stage, also referred to as the oral stage proper, is the phase of swallowing during which the prepared bolus is actively transported from the oral cavity into the oropharynx. This stage immediately follows the oral preparatory stage and represents the final voluntary component of swallowing (Miller, 1982; Logemann, 1998). It begins once the bolus is adequately formed and positioned on the tongue dorsum and ends when the bolus head reaches the palatoglossal arches, triggering the pharyngeal swallow (Figure 3). During this stage, precise and coordinated movements of the tongue play a pivotal role. The anterior tongue elevates to contact the hard palate, forming a seal that prevents anterior bolus escape. Sequential posterior elevation of the tongue against the palate generates a stripping or propulsive action that moves the bolus posteriorly toward the oropharynx (Miller, 1982). This lingual-palatal contact is essential for efficient bolus propulsion and contributes to the generation of positive intraoral pressure required to overcome resistance at the oropharyngeal junction (Ertekin & Aydogdu, 2003).

Simultaneously, the lips remain closed to maintain oral containment, while the buccal musculature stabilises the bolus and prevents lateral spillage into the sulci. The soft palate begins to elevate toward the posterior pharyngeal wall, assisting in directing the bolus downward and minimising premature nasal escape (Logemann, 1998). Although velopharyngeal closure becomes fully effective during the pharyngeal stage, its anticipatory movement during the oral propulsive stage contributes to smooth bolus transit. Neurologically, the oral propulsive stage is under voluntary cortical control, predominantly mediated by motor output from the primary motor cortex via corticobulbar pathways. Cranial nerves V (trigeminal), VII (facial), and XII (hypoglossal) are primarily involved, innervating the muscles responsible for jaw stabilisation, lip closure, and tongue propulsion, respectively (Ertekin & Aydogdu, 2003). Sensory feedback from oral mechanoreceptors further modulates tongue pressure and bolus control, ensuring adaptability to different bolus volumes and consistencies. The duration of the oral propulsive stage is typically brief, lasting approximately 1-1.5 seconds in healthy adults; however, it can vary depending on bolus characteristics, such as size, viscosity, and texture (Mandelstam & Lieber, 1970; Blonsky et al., 1975; Logemann, 1998). Any disruption in tongue strength, coordination, or timing during this stage may result in oral residue, delayed swallow initiation, or premature spillage of the bolus into the pharynx, thereby increasing the risk of penetration or aspiration. In summary, the oral propulsive stage serves as a critical transition between voluntary oral preparation and the reflexively mediated pharyngeal phase. Its efficiency depends on coordinated lingual movements, intact neuromuscular control, and effective sensory feedback, making it a key focus in the assessment and management of oral phase dysphagia (Miller, 1982; Logemann, 1998).

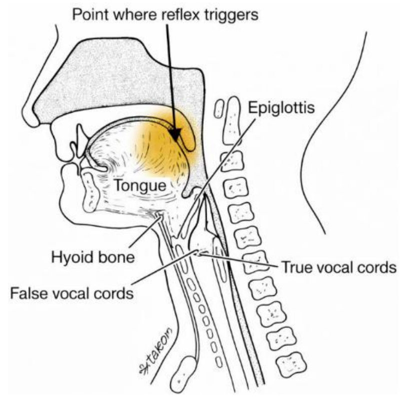


Figure 3. The lateral view of the head and neck illustrating the normal point at which swallowing reflex triggers (Logemann, 2015)

Pharyngeal Stage

The oral stages of swallowing are largely under voluntary control; however, the pharyngeal stage marks the first involuntary step in the swallowing mechanism (Miller, 1982; Logemann, 1998). A cascade of events in this phase is set in motion when the tongue pushes the bolus into the pharynx (Figure 4). The bolus first reaches the palatoglossal arch and anterior faucial pillars, where dense populations of mechanoreceptors and chemoreceptors in the oropharyngeal mucosa are stimulated. Afferent input carried primarily by cranial nerves IX, X, and XI is relayed to the nucleus tractus solitarius in the brainstem, which serves as the primary sensory integration centre for swallowing. The information is then processed within the central pattern generator for swallowing, which integrates the signal and activates a highly coordinated reflex motor response through efferent pathways to the muscles of the pharynx, larynx, and upper oesophagus (Jean, 2001; Ertekin & Aydogdu, 2003).

Once triggered, this stage proceeds in an all-or-none fashion, independent of voluntary control, lasts approximately 1-2 seconds, and terminates as the bolus passes through the upper oesophageal sphincter (UES) (Logemann, 1998). Due to its rapid and obligatory nature, impairment at this stage carries a particularly high risk of airway compromise.

The pharyngeal stage serves two essential functions: safe redirection of the bolus into the oesophagus and protection of the airway (Miller, 1982). Almost simultaneously, elevation of the soft palate by the tensor and levator veli-palatini muscles seals the nasopharynx, preventing nasal regurgitation and allowing efficient pressure generation within the pharynx [ref]. This velopharyngeal closure is essential for building the positive intra-pharyngeal pressure required for effective bolus propulsion (Kahrilas et al., 1992). At the same time, respiration briefly ceases, producing a characteristic swallowing apnea, which typically interrupts expiration and reduces the risk of aspiration. Swallowing is usually followed by expiratory airflow, which further assists in clearing any residual material from the airway entrance. Airway protection is achieved primarily through glottic closure. Inhibition of the posterior cricoarytenoid muscle and activation of the lateral cricoarytenoids result in vocal fold adduction, while contraction of the transverse and oblique arytenoid muscles approximates the arytenoid cartilages (Logemann, 1998). This produces closure at both the anterior and posterior aspects of the glottis. The arytenoids then tilt forward toward the epiglottis, contributing to closure of the laryngeal vestibule. Although the epiglottis itself does not actively seal the airway, its retroversion assisted by tongue base retraction and hyolaryngeal elevation helps divert the bolus laterally into the piriform sinuses and toward the oesophageal inlet (Ekberg & Sigurjónsson, 1982; Steele & Miller, 2010).

Thus, epiglottic inversion functions as a passive biomechanical consequence of surrounding structural movements rather than an active protective mechanism. Concurrently, the hyoid and larynx are elevated and drawn anteriorly by the suprahyoid muscle group. This group includes the mylohyoid, geniohyoid, and the anterior belly of the digastric muscles, and this movement not only enhances airway protection but also plays a crucial role in opening the pharyngo-oesophageal segment (Cook et al., 1989). Anterior-superior displacement of the larynx increases the diameter of the UES and reduces resistance to bolus flow. The bolus is then propelled inferiorly by a rapid, sequential contraction of the superior, middle, and inferior pharyngeal constrictor muscles, creating a cranial-to-caudal pressure wave that moves the bolus toward the UES at a speed of approximately 20-40 cm per second (Dodds et al., 1989). This pressure wave is essential for overcoming UES resistance, particularly when hyolaryngeal excursion is reduced.

The pharyngeal stage concludes as the bolus traverses the upper oesophageal sphincter. At rest, the UES remains tonically contracted to prevent air entry into the oesophagus. During swallowing, it opens through a coordinated sequence involving anterior and superior traction from hyolaryngeal elevation, neural relaxation of the cricopharyngeus muscle, and pressure exerted by the advancing bolus (Kahrilas et al., 1982; Shaker et al., 1997). Failure of any of these mechanisms may lead to impaired UES opening, post-swallow residue in the pyriform sinuses, or aspiration after the swallow.

Successful completion of this phase enables seamless transition into the oesophageal stage, whereas disruption at any point may result in residue, penetration, or aspiration, underscoring the pharyngeal stage's central role in swallowing safety (Logemann, 1998).

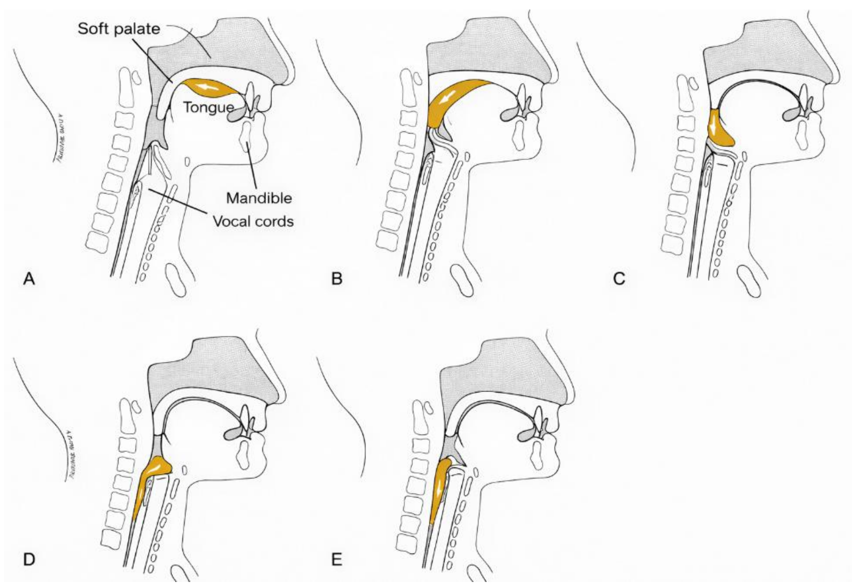


Figure 4. A through E, Lateral views of the head and neck illustrating progression of bolus through the pharynx (Logemann, 2015)

Oesophageal Stage

The oesophageal stage constitutes the final, involuntary phase of swallowing and begins once the bolus passes through the upper oesophageal sphincter (UES), terminating with its entry into the stomach (Figure 5). The oesophagus is a distensible muscular conduit measuring approximately 25 cm in length with an average luminal diameter of about 2 cm, extending from the pharyngo-oesophageal junction to the gastro-oesophageal junction (Miller, 1982; Ertekin & Aydogdu, 2003). At rest, the upper two-thirds of the oesophagus typically remains collapsed, while the distal one-third assumes a rounded configuration, reflecting regional differences in muscular composition and resting tone (Dodds et al., 1990; Logemann, 1998).

Bolus transport through the oesophagus is accomplished by sequential, coordinated peristaltic contractions and is facilitated by gravity when the individual is in an upright position (Ott &Levine, 2015). Compared with the oral and pharyngeal phases, the oesophageal stage exhibits considerable variability in duration, with normal bolus transit times ranging from approximately 8 to 20 seconds depending on bolus consistency, posture, and neuromuscular integrity (Miller, 1982; Ertekin & Aydogdu, 2003).

Oesophageal peristalsis is classically described as primary or secondary. Primary peristalsis represents a continuation of the pharyngeal swallow. It is initiated immediately after bolus passage through the UES, propelling the bolus from the cervical oesophagus to the stomach, typically within 8–10 seconds (Miller, 1982; Dodds et al., 1990).

Secondary peristalsis occurs independently of a pharyngeal swallow and is elicited by mechanical distension or residual bolus material within the oesophageal lumen. This mechanism serves a crucial clearance function, particularly when primary peristalsis is ineffective or incomplete (Goyal & Chaudhury, 2008; Tack & Pandolfino, 2018). Secondary peristaltic activity is mediated through intrinsic reflexes within the myenteric (Auerbach's) plexus, with additional modulation via vagal afferent and efferent pathways to the medulla (Ertekin & Aydogdu, 2003; Goyal & Chaudhury, 2008).

This intrinsic capability of the enteric nervous system allows effective bolus transport even in the absence of an intact central swallowing pattern generator, a phenomenon of clinical relevance in patients with brainstem lesions or neurodegenerative disorders (Miller, 1999; Ertekin & Aydogdu, 2003).

The neuromuscular organisation of the oesophagus demonstrates a distinct longitudinal gradient. The upper one-third consists predominantly of striated muscle under somatic motor control via the glossopharyngeal and vagus nerves, while the lower two-thirds is composed mainly of smooth muscle regulated by vagal input acting through the enteric nervous system (Dodds et al., 1990; Goyal & Chaudhury, 2008). Experimental studies have demonstrated that following vagal denervation, the myenteric plexus is capable of generating effective secondary peristaltic waves after a period of neural adaptation, permitting bolus transit into the stomach even in the absence of normal brainstem control (Ertekin & Aydogdu, 2003).

The UES, formed chiefly by the cricopharyngeal muscle, constitutes a high-pressure zone approximately 3 cm in length at the pharyngo-oesophageal junction. It remains tonically contracted at rest and undergoes brief relaxation during swallowing to allow bolus entry into the oesophagus (Kahrilas et al.,1988; Logemann, 1998). Impaired UES relaxation, reduced hyolaryngeal excursion, or incoordination between pharyngeal contraction and sphincter opening may result in bolus retention within the hypopharynx or piriform sinuses, significantly increasing the risk of post-swallow aspiration an important concern in dysphagia practice (Logemann, 1998; Leonard & Kendall, 2014). As the bolus advances distally, opening of the lower oesophageal sphincter (LES) constitutes the final critical event of the oesophageal stage. The LES is a specialised segment of circular smooth muscle measuring approximately 3 cm in length at the gastro-oesophageal junction and remains tonically contracted at rest to prevent gastro-oesophageal reflux (Dodds et al., 1990; Rosen RD, Winters, 2023). Oesophageal distension by the approaching bolus induces receptive relaxation of the LES, which precedes the peristaltic wave and facilitates unobstructed bolus entry into the stomach (Ertekin & Aydogdu, 2003; Nikaki et al.,2019). Following bolus passage, rapid restoration of LES tone, augmented by intra-abdominal pressure, re-establishes the anti-reflux barrier (Dodds et al., 1990; Rosen & Winters, 2023). Completion of the oesophageal stage is accompanied by re-establishment of resting airway and swallowing postures. The soft palate descends, the hyoid bone and larynx return to their inferior positions, the epiglottis resumes its upright orientation, and the laryngeal vestibule reopens to permit resumption of respiration (Logemann, 1998). Swallowing is normally associated with a brief period of centrally mediated deglutition apnea, most commonly occurring during expiration.

This coordinated timing between respiration and swallowing enhances airway protection and promotes clearance of residual material from the laryngeal vestibule, thereby minimising the risk of aspiration (Martin-Harris, 2005; Ertekin & Aydogdu, 2003). In summary, the oesophageal stage represents a highly integrated interaction between sphincteric function, peristaltic propulsion, and intrinsic and extrinsic neural control mechanisms, ensuring efficient transport of the bolus from the pharynx to the stomach. Disruption at any level structural, neuromuscular, or neural may result in oesophageal dysphagia, aspiration, or reflux-related pathology (Miller, 1982; Logemann, 1998; Ertekin & Aydogdu, 2003).

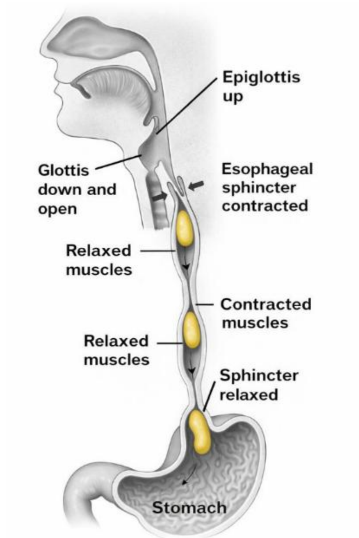


Figure 5. The sagittal view illustrating the oesophageal stage with peristaltic contraction of the oesophageal musculature

Neural Control of Swallowing

Swallowing is a dynamic process that involves precise integration of sensory input and motor output across multiple levels of the nervous system. It involves the coordinated participation of cortical, subcortical, brainstem, and peripheral neural structures to ensure the safe and efficient transfer of the bolus from the oral cavity to the stomach, while maintaining airway protection.

Cortical Control of Swallowing

The cerebral cortex plays a key role in the voluntary regulation of swallowing, particularly during the oral preparatory and oral propulsive phases. Functional imaging and stimulation studies demonstrate that swallowing is governed by a bilaterally organised cortical network rather than a single cortical centre.

This network encompasses the primary motor and somatosensory cortices, as well as the premotor and supplementary motor areas, along with higher-order regions such as the prefrontal cortex, anterior cingulate cortex, frontal operculum, orbitofrontal cortex, and insula (Hamdy et al., 1998; Humbert & Robbins, 2008). Voluntary swallow initiation involves coordinated activation of frontal and parietal cortices.

The oral phase is predominantly linked to the inferior precentral gyrus and posterior inferior frontal gyrus, which regulate tongue, lip, and jaw movements. In contrast, more anterior frontal regions contribute to the modulation of the pharyngeal and oesophageal stages (Daniels & Foundas, 1997).

Although cortical control of swallowing is bilaterally represented, functional hemispheric dominance may exist. This bilateral organisation allows swallowing to be relatively preserved following unilateral cortical injury, though mild impairments in timing, coordination, or bolus handling may still occur (Hamdy et al., 1998).

Role of the Insula and Subcortical Structures

The insular cortex serves as a key integrative centre for swallowing. It links sensory input with motor planning and plays a vital role in regulating swallow timing and coordination. Lesions involving the insula or frontal operculum are frequently associated with dysphagia, supporting the concept of hierarchical cortical control (Humbert & Robbins, 2008; Babaei et al., 2013; Yuan et al., 2015; Wilmskoetter et al., 2020).

Subcortical structures, particularly the basal ganglia and cerebellum, play a crucial role in planning, sequencing, and fine-tuning the complex movements involved in swallowing. These structures influence cortical output and ensure smooth, coordinated execution of swallowing, but do not independently initiate the act (Daniels & Foundas, 1997; Leiguarda et al., 2000; Wilmskoetter et al., 2020; Lapa et al., 2020). While the cortex is essential for voluntary initiation and adaptive modulation, it is not responsible for the moment-to-moment coordination of the swallow sequence. This function is delegated to the brainstem.

Brainstem Control and the Swallowing Central Pattern Generator

The pharyngeal and oesophageal phases of swallowing are controlled primarily by brainstem mechanisms located within the medulla oblongata. These mechanisms collectively form the central pattern generator (CPG) responsible for producing the highly organised and sequential motor output characteristic of a normal swallow (Jean, 2001; Zainaee et al., 2025).

Descending projections from the frontal swallowing areas of the cortex reach the medullary swallowing centres via dorsolateral and ventromedial pathways, travelling through the lateral and ventral corticobulbar tracts. These pathways permit voluntary initiation and cortical modulation of brainstem swallowing activity (Leslie & McHanwell, 2008; Costa, 2018).

Within the medulla, multiple neuronal groups are involved in controlling swallowing. Sensory afferent input is received primarily by the nucleus tractus solitarius and the spinal trigeminal nucleus. Motor output is mediated mainly through the nucleus ambiguus, which supplies the muscles of the pharynx, soft palate, larynx, and upper oesophagus (Miller, 1982; Lang, 2009; Pitts & Iceman, 2023). Two functional swallowing centres have been described within the medulla. The dorsal swallowing group, located dorsally above the nucleus tractus solitarius, is responsible for receiving sensory input and organising the sequential pattern of swallowing. The ventral swallowing group, situated around the nucleus ambiguus, distributes motor commands to the cranial nerve motor nuclei. Together, these centres constitute the functional swallowing CPG (Jean, 1990; Arshavsky et al., 1997; Jean, 2001; Leslie & McHanwell, 2008; Nishino, 2013; Clave & Shaker, 2015; Costa, 2018). Once activated, the CPG generates an automatic and irreversible motor sequence that proceeds independently of further cortical input. This ensures rapid laryngeal closure, effective pharyngeal contraction, and timely opening of the upper oesophageal sphincter, thereby minimising the risk of aspiration (Miller, 1982; Bolser et al., 2013; Panara et al., 2025; Zainaee et al., 2025).

Sensory Afferent Control

Sensory input is fundamental to both the initiation and modulation of swallowing. The oral cavity, pharynx, and larynx contain a rich supply of mechanoreceptors that protect oral tissues during mastication and provide critical information regarding bolus size, consistency, and position. Chemoreceptors and thermoreceptors further contribute to bolus discrimination (Logemann, 1998; Steele & Miller, 2010; Westemeyer & Dietsch, 2024). Afferent impulses are transmitted via cranial nerves V, VII, IX, and X to the nucleus tractus solitarius (NTS) and spinal trigeminal nucleus. The glossopharyngeal nerve and the internal branch of the superior laryngeal nerve are particularly important for triggering the pharyngeal swallow. Impaired sensory input, as seen in ageing or neuropathic conditions, can delay swallow initiation and significantly increase the risk of penetration and aspiration (Humbert & Robbins, 2008; McCoy & Varindani, 2018; Walshe, 2019; Abu-Ghanem et al., 2020). Swallowing may be initiated voluntarily or reflexively. Reflex initiation commonly occurs in response to stimulation of the oral or pharyngeal mucosa, accumulation of saliva, or the presence of food or liquid within the oral cavity.

Motor Efferent Pathways

Motor execution of swallowing involves coordinated output from multiple cranial motor nuclei. Efferent signals arising from the medulla and pons are conveyed through cranial nerves V, VII, IX, X, XI, and XII to the muscles of the lips, jaw, tongue, pharynx, larynx, and upper oesophagus.

The nucleus ambiguus supplies the muscles of the pharynx, soft palate, and larynx, while the hypoglossal nucleus controls intrinsic and extrinsic tongue movements. The motor nuclei of the trigeminal and facial nerves innervate the muscles of mastication and facial expression. Motor neurons within the cervical spinal cord innervate neck muscles involved in hyolaryngeal elevation (Miller, 1982; Leslie & McHanwell, 2008). Bilateral distribution of motor output ensures symmetrical pharyngeal contraction and efficient bolus clearance. Damage to these pathways, as seen in bulbar palsy or brainstem stroke, results in severe dysphagia with marked impairment of airway protection.

Co-ordination with Respiration and Adaptive Modulation

Swallowing is closely coordinated with respiration, with the swallow most commonly occurring during expiration. This coordination reduces the likelihood of aspiration and reflects significant overlap between the brainstem centres controlling swallowing and breathing (Jean,2001).

Continuous sensory feedback during swallowing allows dynamic adjustment of timing and force, enabling safe handling of a wide range of bolus volumes and consistencies. This adaptive capability is essential for normal feeding and is a defining feature of the swallowing mechanism described by Logemann (1998).

Figure 6. Multidimensional neuronal network of the central nervous system controlling the oropharyngeal swallow response and primary peristalsis (Clave & Shaker, 2015; Jani et al., 2018).

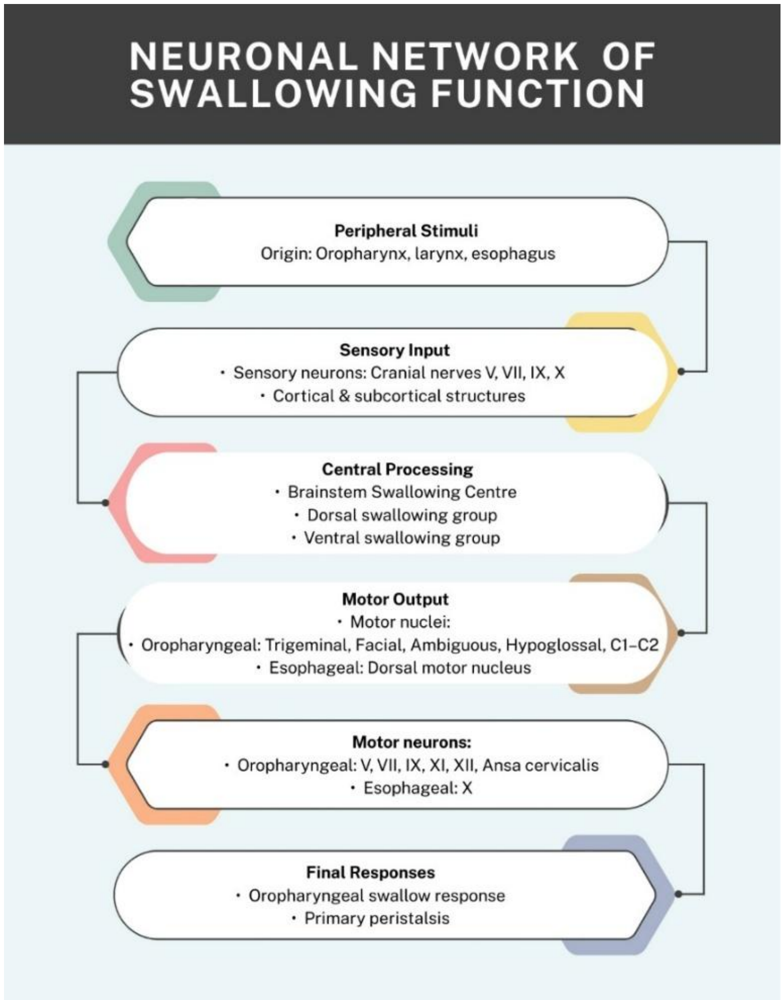
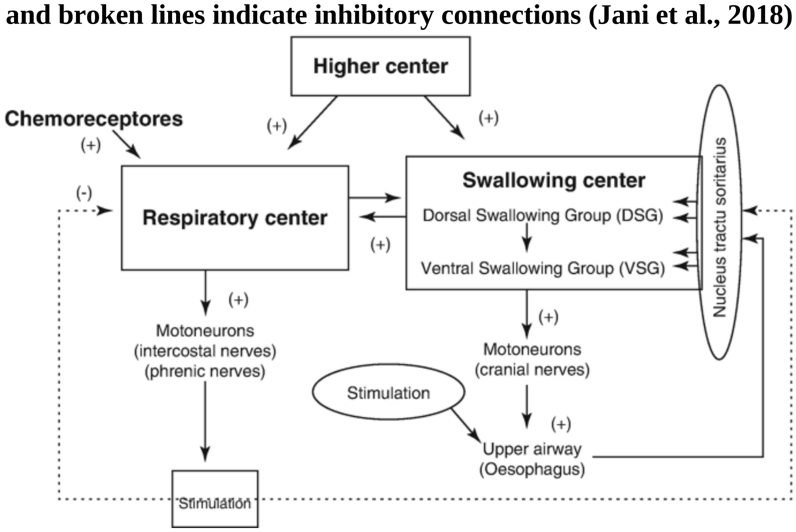


Figure 7. Neural control of reflex swallowing. Solid lines denote excitatory connections, and broken lines indicate inhibitory connections (Jani et al., 2018)



Conclusion

Swallowing is a complex, highly coordinated neuromuscular process that enables safe and efficient transfer of food and liquid from the oral cavity to the stomach while preserving airway integrity. Because the anatomical pathways for feeding and breathing share a common space within the pharynx, precise temporal coordination between these functions is essential to ensure adequate nutrition and to prevent pulmonary aspiration and its sequelae. Understanding the normal physiology of eating and swallowing is therefore fundamental to the evaluation and management of dysphagia arising from disorders of the head and neck, as well as to the development of effective rehabilitation programs.

The swallowing process involves a voluntary oral phase that initiates bolus transport, followed by pharyngeal and oesophageal phases that are largely involuntary and highly stereotyped. During the brief period in which the pharynx is transformed into a conduit for bolus propulsion, rapid and coordinated airway protection mechanisms are critical to prevent respiratory compromise. Contemporary models emphasise swallowing as an adaptive, modifiable motor sequence governed by cortical modulation, brainstem central pattern generators, sensory feedback, and peripheral motor execution. This integrative perspective provides a robust framework for understanding normal swallowing and the pathophysiology of swallowing and eating disorders.

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