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Review

Neurogenic Dysphagia in Brainstem Disorders and EMG Evaluation

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Abstract

Neurogenic dysphagia is a prevalent condition that may result in serious complications. Screening and follow up are critical for early diagnosis, prognosis and management which can mitigate its complications and be cost-saving. Several Neurophysiological methods are described to evaluate the Neurogenic Dysphagia including Single Bolus Analysis, Dysphagia Limit, Cricopharyngeal sphinter electromyogram (EMG), Continuous water swallowing with respiratory recording, Polygraphic recording for spontaneous swallows in awake and sleeping states. All techniques mentioned above were developed in our laboratory. Brain stem disorders are particularly important to investigate the presence of dysphagia due to its high incidence and also its severity. These swallowing methods presented and discussed in this review are reliable, cheap and easy applicable quantitative tests to detect and to follow up both subclinical and clinical dysphagia.

Keywords: Neurogenic dysphagia, oropharyngeal swallowing, ALS, Brainstem, EMG

INTRODUCTION

Swallowing (SW) is a complex sensory motor behavior involving the coordinated contraction and inhibition of the musculature located around the mouth and the tongue, larynx, pharynx and esophagus bilaterally (1, 2). SW is subdivided into three phases. The first phase is the oral phase, which is mostly under voluntary control; the second is the pharyngeal phase, a SW reflex involving striated muscles; and the third is the esophageal phase, which is involuntary and autonomic. The oral and pharyngeal phases are collectively referred to as "oropharyngeal swallowing" (1-3). The majority of neurogenic dysphagia appears in this phase of SW (1, 2, 4).

Neurogenic dysphagia (ND) can result from lesions anywhere along the neuromuscular pathway from the cerebral cortex to the SW muscles (2, 5). Neurological disorders account for about 70% of all patients with SW problems (6, 7). Unfortunately, it is not often considered among the differential diagnosis by neurologists (7, 8).

The main consequences of ND include airway aspirations, which often result in pneumonia, malnutrition, and dehydration that are potentially fatal complications for patients with progressive neurological disorders plus acute cerebrovascular diseases.

ND can be present in insidious and slowly progressive neurological disorders. There may be a subclinical period before the onset of clinically overt dysphagia in these disorders (2). Early diagnosis of ND can enable early establishment of rehabilitation, medical, and surgical management approaches (9, 10). ND with chronic, progressive neurological disorders is submitted to invasive SW tests, especially for the objective diagnosis of aspiration. Invasive tests for dysphagia include videofluoroscopy (VFS), fiberoptic endoscopic examination of swallowing (FEES), manometry, and manofluoroscopy. VFS is considered the gold standard for detection of airway aspiration, however, this technique suffers from problems associated with reliability (6, 7, 11-13). Invasive methods may not be practical for several handicapped neurological patients, such as those with advanced cases with motor problems and dementia. Other concerns related to the VFS approach include its cost, qualitative rather than quantitative nature and lack of easy repetitive follow-up testing. On the other hand, in acute onset neurological conditions, such as stroke patients, the ND often improves spontaneously over a few weeks, i.e., "acute transient dysphagia," and, therefore, they do not need to be investigated by invasive diagnostic tests.

In routine SW studies, it is necessary to start with the EMG methods, and EMG should be the first step in the diagnosis of the presence or absence of ND objectively (2, 4, 7, 9, 14-16).

Brainstem

In this review, I examine the role of the lower brainstem in SW and ND. My topic is limited to disorders directly or indirectly influenced by the lower brainstem, such as acute brainstem infarction, multiple sclerosis (MS) and motor neuron disease.

First of all, the simple organization of the brainstem for swallowing should be discussed. The precise pattern of muscle contraction and inhibition sequentially for oropharyngeal swallowing is dependent on the brainstem neural structures. They conceptually consist of three levels:

I-An afferent and/or descending input level that corresponds to termination sites of peripheral and central swallowing afferent fibers.
2-An efferent level that corresponds to the motoneuron pools of the cranial motor nuclei that provide innervation to SW muscles.
3-An organizing level that consists of an interneuronal network or "premotor" neurons and is in contact with both afferent and efferent levels.

These premotor neurons and/or interneurons that can initiate or organize the swallowing motor sequence are known as the SW Central Pattern Generator (CPG) (3, I7-23). SW premotor neurons are located within the nucleus tractus solitarius (NTS), the adjacent reticular formation around and just above the nucleus ambiguus (NA) of the ventrolateral medulla oblongata (3, I7, I8, 20, 22).

Thus, the SW interneurons or premotor neurons are located in these two main brainstem areas: the dorsal SW group (DSG) in and around NTS and ventral SW group (VSG) just above the NA (Figure I) (3, I8, 20, 23).

SW premotor neurons might be involved in the bilateral and rostro-caudal coordination of the multiple motoneuron pools within the SW-network in the medullary level. VSG neurons are activated via DSG neurons, and all motoneurons of SW in the V, VII, IX, X, and XII motoneuron pools are driven by the premotor neurons of the VSG (3, I8, 22). The DSG contains the generator neurons involved in the triggering, shaping and timing of sequential or rhythmic SW pattern. The VSG contains the switching neurons that distribute the SW drive to the various pools of the motoneurons involved in swallowing (I, 3, 22). These premotor neurons excite the motoneuron pools bilaterally from VSG.

The CPG for SW consists of two hemi-CPGs each located on one side of the medulla. Under physiological conditions, the two hemiCPGs are tightly synchronized and organize the contraction of the bilateral muscles of the oropharynx (3, I8, 24). Anatomical connections mediated by nerve fibers crossing the midline have been found to exist between the two medullary regions where the SW neurons are located in the DSG and VSG. Thus, the SW motor sequence is mainly generated in the ipsilateral hemi-CPG, and this CPG transfers the SW premotoneuronal signals to the contralateral CPG (3, I8, 24). SW NTS neurons play a crucial role in these synchronization processes.

The dual SW centers on both sides of the medullary region and their extensive connections are important in understanding the nature of dysphagia in Wallenberg Syndrome in humans. We will discuss this syndrome in detail later (Figure 2).

Voluntary versus Spontaneous Swallowing

In NTS, the premotor neurons are known to receive convergent information from both cortical and peripheral inputs that trigger swallowing (3, 22). This kind of information is important, firstly, for the voluntary-induced swallow. In these feeding actions, the first cortical input is thought to descend to the neurons of the NTS. Thus, sequential eating and drinking may be voluntarily initiated or facilitated by the cerebral cortex by means of the neural network (CPG) at the brainstem (I, 25-27). In voluntary induced swallow or voluntary swallow (VS), the regions of the cortex and subcortical areas involved with SW serve mainly to trigger deglutition and to control the onset of the motor sequences, i.e., mainly the oral phase of SW (27). After this, sequential muscle activation is carried out without any further cortical control to perform the pharyngeal and esophageal phases (I, 3, 25-28). In contrast to VS, there is also swallowing action after mealtime without awareness and during sleep in humans without any feeding purposes, and this is called spontaneous swallowing (SS) or reflexive SS (22, 27, 29, 30). However, SS has rarely been studied in humans compared to VS. It is important to emphasize that although the initiation of VS is planned, its pharyngeal phase is a reflex. Therefore, it should not interfere with SS. There is no strong evidence of a cortical influence on SS in humans.

Figure I. Schematic diagram of Central Pattern Generator of the Network at the Medullary level (Modified from Jean 2001 and Ertekin Aydogdu 2003).
NTS: Nucleus Tractus Solitarius, NA: Nucleus Ambiguus, DSG: Dorsal swallowing group, VSG: Ventral swallowing group

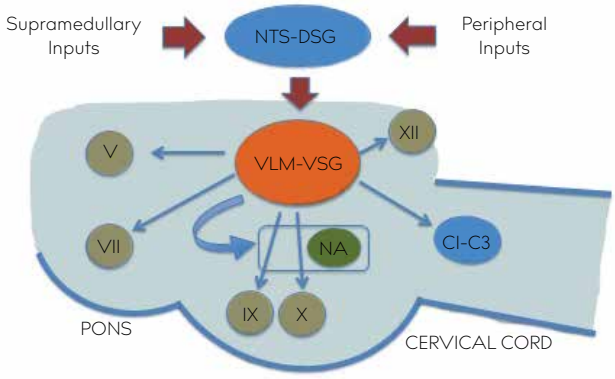
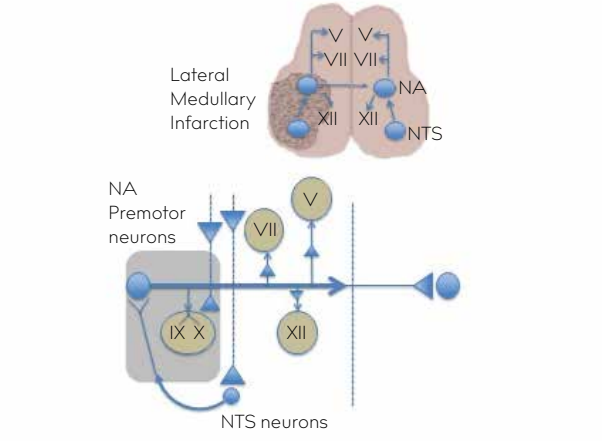


Figure 2. Deglutition associated connectivity of the medulla oblongata. Top figure: Both sides of the swallowing centers and their connection with cranial nerves nuclei. Bottom figure: Schematic representation of premotor neurons and their ipsilateral connection to the cranial motor nerve pools and the contralateral swallowing center.
Shaded area: affected lateral medullary infarction (LMI) and the involvement of the NTS and NA at the medullary level (Modified from Aydogdu et al., 2001)



SS is composed of periodic swallowing movements spread out over 24 hours (27, 31-34). The pacemaker for SS seems to be related to the CPG of the brainstem network (17, 18). However, in some situations, the alteration of the SS may be related to some subcortical regions (2, 27, 31). Therefore, SS can generally be accepted as an action of the lower brainstem, and I will discuss SS rather than VS. However, SS is a saliva swallow and is a protective reflex action to ensure the safety of the upper airway tract against the escape of food particles or saliva (22, 29, 35). We have stressed that SS is under the control of the medullary network of CPG and bypasses the cortical drive (1, 30). The CPG does not only function to control the pharyngeal and esophageal phases of SS but also portions of the oral phase (27, 30, 36). The pontine trigeminal nucleus and reticular formation may also contribute to SS (27, 36, 37). Therefore, the SW muscles, such as masseter, orbicularis oris, and submental/suprahyoid muscles, used for the VS-EMG studies can also be electrophysiologically evaluated in SS studies.

How to evaluate the brainstem function by EMG methods:

Although the SS seems to be important in the evaluation of ND, the VS should firstly be examined by all neurophysiological methods described previously (34). In order to understand the role of EMG in the oropharyngeal SW, we should shortly review the successive events during VS.

The first event is the triggering of the SW reflex that occurs at the oropharyngeal cavities by the bolus, which produces sensory input that travels up the brainstem and cortex (14, 27, 38).

The second event is the elevation and closure of the larynx and soft palate for airway protection together with the contraction of the submental/suprahyoid muscles situated under the chin (1, 14, 39).

The third is the propulsive, pumping force of the tongue and sweeping function of the bolus on the constrictors of the pharynx (39-41).

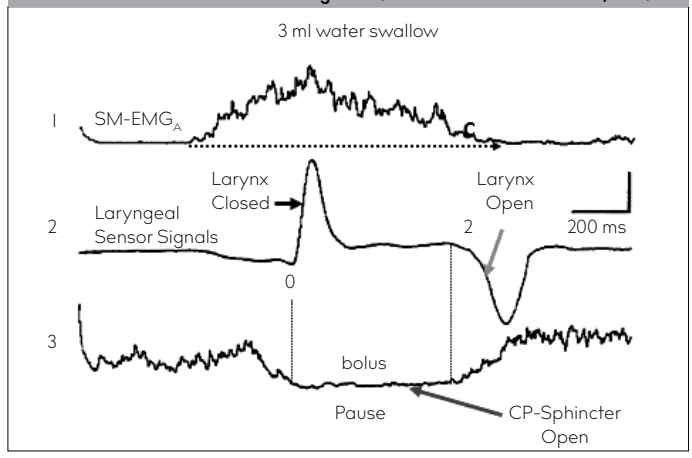
The last event is the relaxation and opening of the cricopharyngeal muscle of the upper esophageal sphincter, which is normally closed at rest. As a result, the bolus is transported into the esophagus (9, 14, 42, 43).

The following EMG methods can be used to investigate the nature of the SW and its disorders that we call single bolus analysis (Figure 3).

1-The onset and duration of pharyngeal swallowing is recorded from submental/suprahyoid muscles (SM-EMG). SM muscles fire concurrently to initiate oropharyngeal SW. For SM-EMG, the surface electrodes are usually placed 1 cm lateral to the midline bilaterally under the chin (14, 44).

2-A piezoelectric sensor placed between the thyroid and cricoid cartilages can monitor the upward/downward movements of the larynx during SW. This method provides data about the timing of laryngeal elevation during the pharyngeal phase of the reflex response, or one may use routine EEG electrodes over and above the thyroid cartilage (31, 32).

Figure 3. Single bolus analysis (SBA). Three milliliters of wa¬ter swallowed by a normal control. 1: Submental EMG (SM-EMG). The EMG trac¬es are the averages of five responses. 2: Laryngeal sensor signal. 3: Cricopharyngeal sphincter muscle (CP-EMG). Amplitude cali¬bration: 20 μV and 100 μV in (1) and (3), respectively. Time calibration: 200 msec in all traces. EMGs are rectified and integrated (Modified from Ertekin et al., 1995)



3-EMG activity of the cricopharyngeal sphincter (CP) muscle in the upper esophageal sphincter (UES) can sometimes be recorded with a concentric needle electrode inserted percutaneously and directed postero-medially in the neck (CP-EMG) (9, 14, 42, 43).

4-For the SS, the surface recording of the perioral lip muscles and masseter muscle is also used (2, 4, 9, 32).

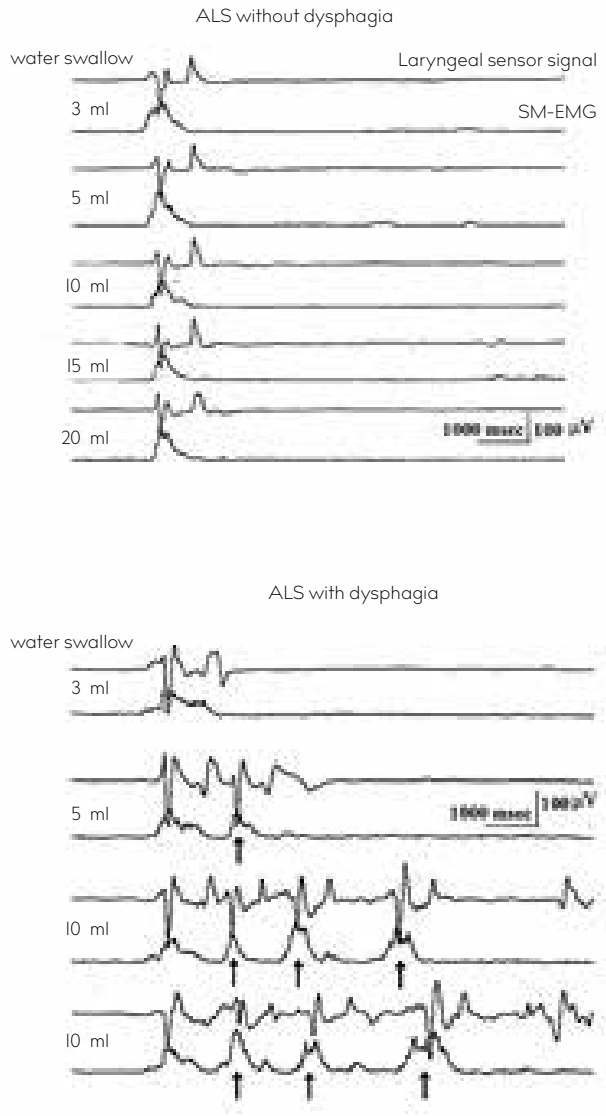
As a routine SW study, we have to start with the "Single Bolus Analysis" as demonstrated in figure-3 and the "Dysphagia Limit" that will be discussed. These SW-EMG methods are necessary and the first steps in the diagnosis of ND (9, 14, 15, 45).

The dysphagia limit was previously described (7, 9, 15). This is a method to measure the maximum power of drinking water in one go. For this purpose, the SM-EMG and laryngeal movement sensor are used, but sometimes the respiratory signals are included in the method. All of the normal adult subjects swallow an amount of 20 mL or more, but the ND patients could not pass the 20 mL of water and lesser amounts of water may produce piecemeal deglutition. The 5, 10, 15, and 20 mL of water are delivered step by step. It is easy and quick test, and you may record the evaluation. It is practical to follow-up patients. The piecemeal deglutition and dysphagia limit are based on the detection of a physiological phenomenon that occurs when an oral bolus of large liquid volume is divided into two or more parts that are then swallowed successively. Any duplication or multiplication of swallowing at or below 20 mL of water is considered to be pathologic and patient dysphagic (Figure 4). Some other methods will be described within the disorders of the lower brainstem.

Brainstem Disorders:

The lower brainstem, especially the medulla oblongata, is a very important organ, and any acute traumatic lesion involving the medullary region is life-threating. Therefore, the ponto bulbar region has only a few diseases that can involve a long survival or enough time for necessary clinical and instrumental investigations. Among these, two diseases are amenable for diagno-

Figure 4. Dysphagia limit (DL). Upper traces are from an amyotrophic lateral sclerosis (ALS) patient without dysphagia, and DL is normal. Lower traces are from an ALS patient with dysphagia, and DL is 5 mL and pathological (Modified from Ertekin et al., Brain, 2000)



sis and care of patients. One of them is the lateral medullary infarction (LMI) or Wallenberg syndrome that is mostly a favorable prognosis. The second disease is the motor neuron disease (or ALS), which unfortunately carries a bad prognosis. It is well known that dysphagia is a common consequence of brainstem stroke, and it is typically associated with a greater likelihood of occurrence when compared with hemispheric strokes (44). It is noted that 47% of patients with brainstem stroke suffered from dysphagia, and aspiration was demonstrated in about 40% of them (46). A lower brainstem stroke is believed to have a direct effect on the swallowing centers (NTS and NA) and the lower motor neurons. As a consequence, dysphagia following brainstem stroke is often more severe, and the chances for spontaneous recovery are less likely compared with ND following a hemispheric stroke (47). Still, there are only a few studies reporting the incidence of dysphagia in brainstem infarction patients except LMI (24, 48-50). In our unpublished study, Beckmann et al. (51), we demonstrated that dysphagia was as high as 21% in acute brainstem infarction patients who claimed the complaints and signs of ND (Total of 53 patients). However, when we applied our electrophysiological method on the first days of stroke, there were subclinical or mild dysphagic in more than half of the patients. Thus, the electrophysiological methods are highly sensitive for revealing the potential occult swallowing symptoms in the early days. We called it "early transient dysphagia." Dysphagic findings were minimal in mesencephalic infarction, but pontobulbar involvement has shown more severe cases. The transient dysphagia in lower brainstem infarction is not clearly known at the present, but LMI with dysphagia in the early period regional disconnection in between two swallowing networks or centers may be as severe as described in the chronic Wallenberg Syndrome and produced severe pharyngeal dysphagia (Figure 2) (24). Dysphagia in LMI is also shown to be frequent in cases with more rostral lesions (50). Others have proposed that plasticity occurs by cortical connections in LMI (52). Classically, LMI demonstrates more dysphagia compared to medial medullary infarction (MMI) (53). It is interesting that pontine infarction was the most frequent group in our patients (56% of all cases investigated), and they are all unilateral. Probably the pontobulbar trigeminal system would be one of the mechanisms to prolong the duration of SW, if the pontobulbar trigeminal afferent system has impaired input arising from oropharynx, trigeminal-maxillar, glossopharyngeal, and vagal nerve branches that innervated the oropharyngeal muscles that have sensory inputs coming up to the pontobulbar region. Any sensorial impairment in the system may produce dysphagia and aspiration in stroke patients (54, 55). Therefore, in pontine infarction, the trigeminal system is partly affected in the pontine lesion. A minor contribution to dysphagia can come from unilateral facial paresis encountered in some pontine lesions (54, 56). Probably the afferent and efferent routes of swallowing have processed slower conduction rather than the central abnormality within the CPG of the medullary SW network.

In acute pontobulbar vascular involvement, the transient dysphagia or subclinical dysphagia can be investigated by electrophysiologic methods when the patient is not in the intensive care unit. In these circumstances, two new methods were recently developed by us beside the dysphagia limit and single bolus analysis. These two techniques for the evaluation of swallowing are sequential water swallowing (SWS) and polygraphic evaluation of the spontaneous swallowing (SS).

Sequential Water SW and Brainstem Disorders:

Continuous sequential SW from a cup or straw in humans has been recognized as a more physiologically appropriate approach to evaluate the physiology of deglutition and diagnosis of dysphagia. SWS is a common daily occurrence characterized by multiple successive, rapid swallows (16, 57-59). SWS is technically similar to the "3 ounce test" and "timed test," but these two SW tests are performed by clinical observation during which 90-150 mL of water should be swallowed as fast as possible without interruption (60, 61). SWS is assessed either by the collection of radiological (57, 62) or physiological recordings (16, 63, 64). During SWS, there are rhythmic or pseudorhythmic SW sequences with-

out any clinical pause. When recordings of SWS are collected while using a nasal airway sensor for respiration and SM-EMG, we can observe approximately 1 sec interswallow intervals between each couple of swallow deflections in the SM-EMG, during which the respiratory recordings demonstrate breath holding that results in a swallow apnea period in normal subjects.

The advantage of recording SWS is to closely and objectively follow the relationship between swallowing and breathing. This approach also has more advantages for evaluation of aspiration problems because after the first SW in SWS, the subsequent swallows are primarily initiated at the hypopharynx in normal subjects who are most prone to producing laryngeal penetration (57, 62). When the water volume is increased for SWS, laryngeal penetration or aspiration frequently occur (65, 66). There is also the report of an effect of aging on SWS with laryngeal penetration occurring more frequently in older adults (62).

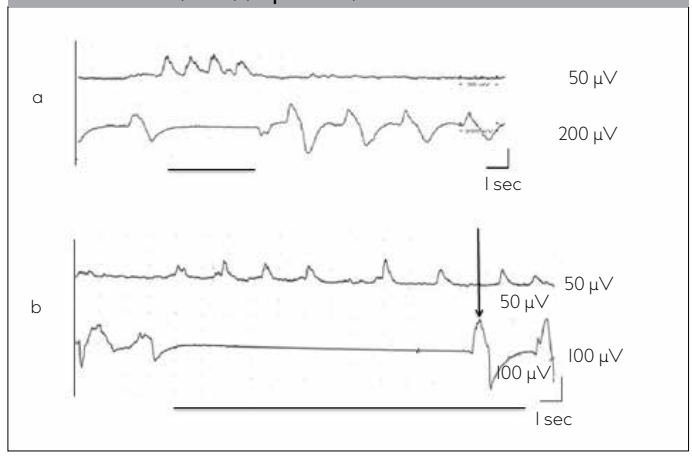
The physiological method of SWS was previously described (16, 63, 64). Briefly, subjects are instructed to drink 50 mL of water from a cup continuously as "in daily life." The water temperature is usually 25°C. The "Start" command for SWS is given a few seconds after the EMG traces appeared on the screen. The total analysis time was 20 seconds. The following parameters were measured:

1-The number of SWs during drinking.
2-The total duration of continuous drinking of 50 mL water.
3-Total duration of swallowing apnea during 50 mL SWS.

In Figure 5, one can see 50 mL SWS of one adult healthy control and a dysphagic patient with pontine infarction. In 5A, the healthy adult control was normal in SWS and his swallowing apnea period, while in 5B, the total duration of continuous drinking and swallowing apnea were pathologically prolonged in the dysphagic patient. In addition to the prolonged SWS and SW apnea, there are two other pathological signs that occurred during this SWS test. Number 1: the swallows are irregular, and the normal rhythmicity is lost. Number 2: compensatory two respiratory deflection immediately appeared probably due to compensation of the prolonged SWS apnea. These kinds of electrophysiological signs occurred frequently in pontobulbar infarction, as is seen in Figure 5b. The arhythmic SWS and compensatory respiratory cycles during swallow intervals were the most important dysphagic components of the brainstem infarctions (16, 51, 63). Although it is not systematically studied, the cardiac rhythm also has influence in some patients with Wallenberg syndrome (LMI).

If we summarize the features of SWS in brainstem infarction and other patients with ND, especially for ALS, the most frequent findings are the prolongation of SWS and sometimes an increase in the number of swallows (16). The SWS apnea period is prolonged with the same extent of total SWS duration. However, the most important finding is the occurrence of compensatory respiratory cycles in between irregular intervals of the swallows (Figure 5). It is not uncommon to record the compensatory respiratory cycle between the last interswallow interval of SWS, even in normal subjects. However, in ND and brainstem involvement, compensatory respiration can also be recorded in the midst of SWS during the apnea period of swallowing. The compensatory

Figure 5. a, b. 50 mL sequential water swallowing (SWS). (a) Normal adult case with short duration of SWS and swallowing apnea (Underlined). (b) Dysphagic patient with unilateral pontine infarct at the first week of stroke. SWS and SW apnea are prolonged, and the number of SW is increased. Note the compensatory respiration cycle at the lower trace (arrow) (Unpublished)



respiratory cycles during apnea periods are often recorded only once, but they increased in the patients of ND (4, 64). This finding may be important, and it may show the early period of airway aspiration. All simple, screening, non-invasive tests for detecting ND are necessary to prevent unwanted complications, including aspiration pneumonia (6, 67). As we mentioned again, the most encountered abnormality was the prolonged duration of SWS of 50 mL water. Probably the pontobulbar trigeminal system would be one of the mechanisms to prolong the duration of the sequences of swallowing.

Brainstem and ALS:

Another important disease of the lower brainstem is the motor neuron disease (ALS). ALS is somewhat well known for its anatomopathological distribution in the brainstem and spinal cord where the progressive degeneration of the cortico-bulbo-spinal tract and the loss of bulbospinal motor neurons are common (68). The role of the SW-CPG is not precisely known in normal human subjects with ND. Furthermore, the involvement of the interneurons in ALS has not been clearly shown (68, 69). Evidence of neurodegeneration of the pontobulbar motor neuron pool was experimentally demonstrated (70, 71). The central proportions of the oropharyngeal sensory afferents connect with the interneurons of the NTS, which comprises the sensory motor nucleus of the swallowing CPG that is responsible for orchestrating, triggering, shaping, and timing the sequential motor pattern of the pharyngeal stage of swallowing (3). CPGs lack the central command hierarchy from the higher centers; their functional role can be presumed to deviate. For instance, spasticity can be encountered in some patients with ALS owing to the dysfunction of the spinal interneurons (72). Similarly, lack of corticobulbar control on the SW-CPG may produce a functional disturbance within the CPG, such as generating premotor neurons around the NTS where they produce the timing and shaping of the swallowing, especially sequential swallowing (3, 22). In ALS patients, the most novel finding is the arhythmical or irregular pattern of SW intervals during SWS in 43% of ALS patients (16). Coordination of respiration and SW or only the SW process is disturbed, and respiration is still normal. It can be concluded

that the dyscoordination in between respiration and SW did not allow continuous swallowing because the physiological SW apnea period could not be tolerated by the patients during irregular and longer stops between swallow bursts. The respiration cycle could be evoked by irregular intervals between consecutive intervals. The arhythmical SWS patterns can be considered as a kind of dysfunction of CPG of the medullary SW center (4, I6, 73) (Figure 6).

The cortico-bulbar fibers involved and the motor and premotor neuron disconnection may also find support in some other dysfunction of ALS patients. Figure 7 demonstrates that hyperreflexic CP is a type of EMG abnormality of the CP sphincter mostly encountered in ALS, suprabulbar palsy with lacunar infarct (73, 74). The findings characterizing a hyperreflexic CP sphincter are shortening of the CP-EMG pause, premature closure before the descending movement of the larynx and unexpected EMG bursts during the CP-EMG pause. However, the motor neurons and motor units of the CP muscle seem to be normal in ALS (75).

The rarity of the lower motor neuron involvement of the CP muscle may be open to discussion. However, in ALS, other sphincters, for instance the anal sphincter, are almost spared from the lower motor involvement. We may make an analogy for the CP sphincter for this point. Whatever the reason, the classical needle EMG study should be done carefully and systematically whether the partial denervation does exist or not.

One other point is that the spontaneous swallow cannot be stopped in ND, including ALS, hence, the patterned but spontaneous swallow could be performed. However, the hyperreflexic CP sphincter could be a secondary handicap for ALS patients even though SS is produced. So, in advanced cases of ALS, there is a strong need for the percutaneous endoscopic gastrostomy (PEG).

Polygraphic SS recording and Brainstem Disease

Spontaneous swallowing (SS) is a saliva SW that occurs without the person being aware, such as between meals and during sleep (27). SS is either a protective reflex action to ensure the safety of the upper airway tract against any escape of food particles or saliva (27, 29, 35). It is often accepted that SS is under the control of the medullary network of the central pattern generator (CPG) and bypasses the cortical drive (I, 30). The CPG is not only to control the pharyngeal and esophageal phases of SW but also a portion of the oral phase (30, 32). The pontine trigeminal nucleus and reticular formation may also contribute to the control of SS (36, 37). When a study is related to SS, the pontomedullary region in the brainstem should be taken into account.

Spontaneous swallowing is composed of periodic movements spread out over 24 hours (27, 3I, 75, 76). During an awake state, healthy subjects swallow saliva frequently at a rate of about once a minute (32, 76), and even lower counts of SS are reported (3I, 33, 34, 75). This rate of SS may vary due to different factors, especially those influencing saliva production from the salivary glands around the oral cavity. For example, after a meal or drinking a cup of water, the rate of SS increases (3I). The rate of SS slows during

Figure 6. a, b. **I00 mL sequential water swallowing (SWS). (a) Normal control subject with normal SWS and SW apnea duration. (b) Dysphagic patient with ALS. SM-EMG is tremendously prolonged and arhythmical. Respiration compensates for swallow irregularity (Unpublished)**

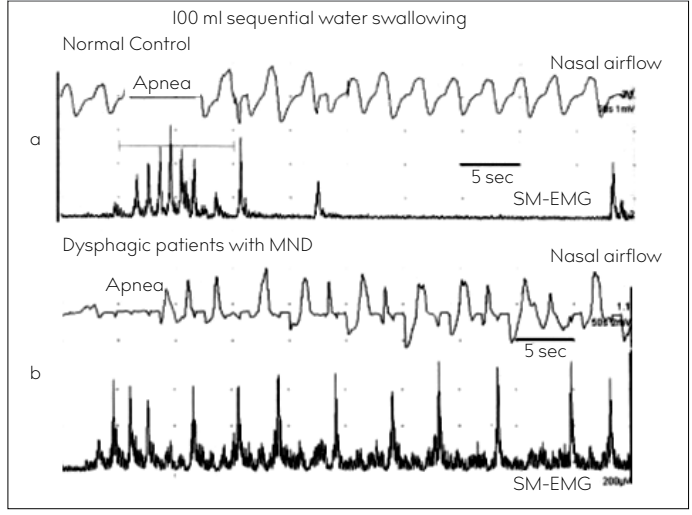
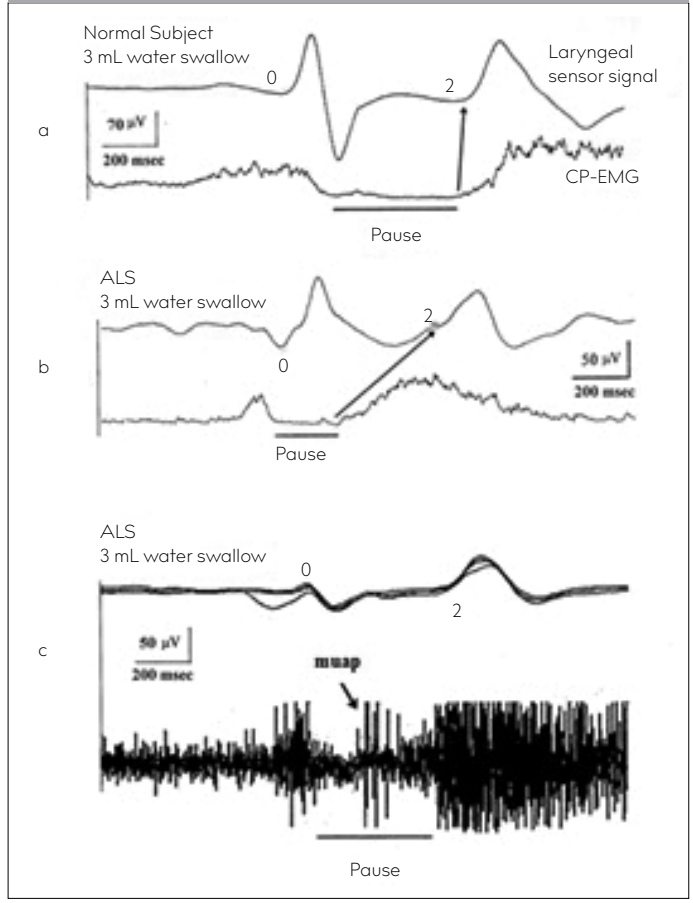


Figure 7. a-c. **Hyperreflexic cricopharyngeal (CP) sphinc¬ter electromyogram (EMG). Two amyotrophic lateral sclerosis (ALS) patients with dysphagia (b and c). Dur¬ing swallowing, the duration of the CP-EMG pause is shorter, and the CP-EMG pause ends prematurely be¬fore the larynx descends from its superior position (b). The unexpected burst of motor units during the CP-EMG pause of the CP sphincter is clearly recorded (c) (see the arrows and compare them with the normal control shown in a). The last trace is the result of con¬ventional EMG (Modified from Ertekin et al., 2000).**



sleep, especially in the slow-wave stage (76-78). In most adult subjects, SS is simultaneously recorded with some EEG arousal (76, 78). Even in the stages of sleep, the rate of SS is significantly changed and SS is tremendously reduced in REM and non-REM 3 stages (76). The coordination of breathing and SW is especially important during sleep. The triggering mechanism is frequently imperfect, and it has been reported that most healthy adults experience nightly aspiration of pharyngeal secretions during sleep (79). We mentioned that the pacemaker for SS seems to be related to the CPG of the medullary SW centers (3, 18, 22). However, in some situations, alteration of the SS may be related to some subcortical/extrapyramidal system (2). The rate of SS in the elderly is slower than that in young adults (32). We have developed a polygraphic technique for the continuous evaluation of SS using one-hour recordings (32). Any routine EEG apparatus can be used for this technique, and we used a 12 channel EEG device. Five channels are used to record the EMG signals, namely orbicularis oculi (OC), orbicularis oris (OR), submental muscle group (SM), masseter muscle (MS) and sometimes tibialis anterior muscle (TA). It was necessary to use one channel for the laryngeal sensor for vertical movements of the larynx during SW. One other channel is to record the respiratory signals from a nasal cannula (for technical details see the article: Ertekin et al. (32)). SS data are included according to the following criteria (32):

1-The OR, MS and SM muscles fire together and sequentially in a burst that lasts 1–3 seconds. The SM-EMG is often highest in amplitude during this activity.
2-All three SW muscles mentioned above must be recorded in parallel with a synchronous, laryngeal sensor deflection indicating vertical movements of the larynx during SW.
3-During recording, one of the investigators ensures the upward/downward movement of the thyroid cartilage and other SW movements, preferably using a video-EEG recording.
4-In all three muscles, the response amplitudes for deglutition must be at least four times higher than the baseline.
5-The nasal airway sensor is used because the SW activity should occur during the apnea period of respiration (Figure 8).

After such a continuous SS recording, we found some novel physiological/pathological findings:

a) The orbicularis oculi (OC) was synchronously activated with spontaneous and even voluntary swallows. This synchronous activation of OC is less prominent in voluntary discrete SW. It is proposed that this might be based on trigemino-solitarii-facial pathways with a weaker connection to the OC muscle (80). This kind of trigemino-solitarii-facial connection to the pontobulbar region is functionally demonstrated (32) (See explanatory diagram in Figure 9).

It was concluded that the large area of intraoral mucosae and teeth innervated by the trigeminal nerve afferents contribute to the muscle of deglutition, including OR. The OC motoneuronal pool can be expected to be excited by this oral input given the neuroanatomical proximity of the OC and OR brainstem nuclei. The OC and OR motoneurons could be connected by the intraoral trigeminal nerve system to the brainstem trigeminal afferent structures of the facial motoneurons via a deglutitional center like NTS or CPG. There is no doubt that the OC activity during

Figure 8. **One-hour polygraphic recording of spontaneous swallowing. A normal adult control. Two successive swallows occur with the apnea. Please note the activation of swallowing plus orbicularis oculi synchronously (Unpublished)**

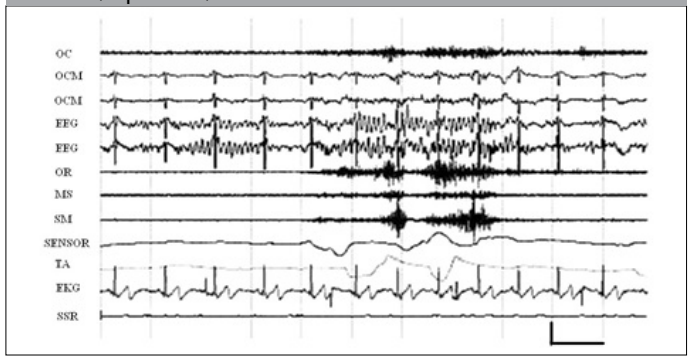
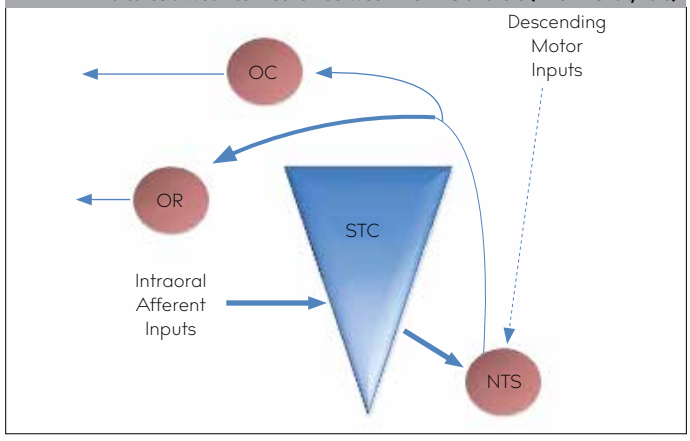


Figure 9. **Schematic diagram illustrates the proposed anatomical basis of swallowing-induced OC–OR synchronization. Only one side of the brainstem is depicted. OC orbicularis oculi muscle, OR orbicularis oris muscle, STC sensory trigeminal complex, NTS nucleus tractus solitarius. Dotted line denotes descending tracts related to voluntary swallowing. The thin line indicates a weak connection between the NTS and OC (Ertekin et al., 2013)**

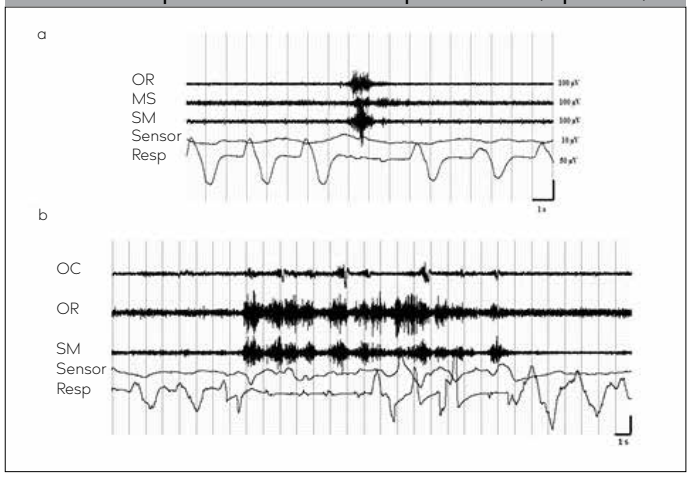


swallowing is distinct from blinking. This novel finding in humans opens an area for several clinical and evaluation problems to be elucidated.

b) One important feature of SS observed in both healthy control subjects and patients with brainstem infarction was a tendency to appear as *double* or *triple swallows* with 1 or 1.5 second intervals between the swallows. Since the double or triple SSs are frequently observed in both normal subjects and brainstem infarction, they are not accepted pathological signs, but their frequency should be differentiated in future studies.

c) In polygraphic recordings, the most abnormal qualitative new finding was the "salvo type of SS," and this was not described before except in our recently published article (76) and in our previous reviews (2, 4). Salvo type of SS can be described as the occurrence of 4–20 consecutive swallows in a single set as a salvo. The interval between two swallows is usually less than 2 seconds. They start and stop suddenly. Shorter salvo swallows are associated with a prolonged apnea period, but the increased number of swallows in the salvo could be continued by some compensatory respiratory cycles after the first 4-5 swallows (4-6). They sometimes appear in a regular rhythm, but sometimes they were arhythmical with 0.5-2 second intervals (Figure 10).

Figure I0. a, b. Polygraphic recording. (a) Single SS from a normal adult case. (b) Patient with brainstem infarction. Salvo type of consecutive SSs. Note the SW apnea is partly prolonged and compensatory respiration is recorded in the last part of salvo SS (unpublished)



The salvo type of SS is mostly but not always recorded in patients with ND, such as brainstem infarction (unpublished study) and Parkinson's disease, and we also observed this kind of SS in multiple sclerosis patients (2, 76). According to our estimation from I24 patients (Parkinson's disease, multiple sclerosis and brainstem infarction) and 74 age-matched normal adult controls, the salvo type SS was found in about 4% (3 normal controls), while patients had salvo swallowing in more than 36% of patients (45 patients). There is a significant difference between the two groups when we compare the one-hour polygraphic recording. However, such a short period may not be enough to draw a conclusion of the salvo type of SS because in an all-night sleep study revealed that the salvo swallowing was found in 7I.4% of patients with Parkinson's disease (45 patients) versus only 2 normal subjects demonstrated some salvo swallowing during all night sleep (about I%) (76). Salvo SS does not seem disease-specific, and salvo type SS may be a non-specific pattern related to subclinical and clinical dysphagia (76). However, many individuals with brainstem and basal ganglia involvement can have silent aspiration with little awareness of their dysphagia and little or no cough response to aspiration. Although no clear polygraphic pattern can be identified for silent aspiration (2, 76).

The salvo types of SS are probably missed because the SW studies have been performed for VS and often in a sitting position and mostly awake situations with a short time period. As a result, the salvo types of SS observed in sleep recordings could not be demonstrated previously.

CONCLUSION

We propose that the electrophysiologic methods mentioned in this review for the evaluation of SW and the brainstem are non-invasive, reliable, cheap and simple quantitative tests to detect and follow up both swallowing and its disorders. They can be performed in a clinical neurophysiology laboratory. However, using these methods, we need to explain the meaning of some phenomena that appeared in the study. It is therefore necessary to work to illuminate the functional connections between the oropharynx and the lower brainstem.

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