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TOPIC HIGHLIGHT

New Techniques-Future

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ABSTRACT

Swallowing problems (dysphagia) are common after brain injuries such as Stroke, and can affect as many as 78% of patients in the period immediately after the injury. In some cases, compensatory recovery processes within the body can accommodate and restore a patients swallowing ability to a safe level within weeks of the brain injury. However, during that often protracted recovery period and in those patients who do not recover naturally, dysphagia can lead to serious morbidity, in particular malnutrition and pulmonary aspiration. Despite this, swallowing therapies remain controversial, with limited evidence base and little in the way of objective outcome measures that provide scientific support for their use. However, better technology and an increasing use of neurophysiological imaging and stimulation techniques have helped to improve our understanding of the cortical control of swallowing. Moreover, experimental treatments involving central and peripheral stimulation are now attracting a great deal of attention as a means to help some patients recover their swallowing to a safe level. This article will review some of the newer techniques potentially suitable for the treatment of dysphagia after stroke.

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Key words: Dysphagia; Recovery; Rehabilitation; Stimulation, therapy

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INTRODUCTION

Stroke is a major cause of disability and the third most common cause of death in the European Union with recent research showing 50%-78% of stroke patients are affected by dysphagia[1] and that up to 40% of these patients remain dysphagic a year later. Aspiration pneumonia is a common consequence of dysphagia[2-8] and carries a significantly (×3) increased risk of morbidity and mortality[2,3,9]. Moreover, neurological causes of dysphagia often lead to patients requiring enteral nutrition[10-11] and increase the need for long-term institutionalised care[12].

Nevertheless, given sufficient time, a proportion of dysphagic stroke patients eventually recover the ability to swallow again[3]. The mechanism for this recovery, seen in many of the initially dysphagic stroke patients has, however, remained controversial. However, in a seminal study of swallowing in stroke using TMS, both dysphagic and non-dysphagic patients had the cortical topography of their pharyngeal musculature serially mapped over several months[13]. Results from an earlier study by the same authors[13] taken together with a follow-up study[14], showed that the cortical map representation of the pharyngeal musculature in the undamaged hemisphere markedly increased in size in dysphagic patients who recovered swallowing, whilst there was no change in patients who had persistent dysphagia or in patients who were non-dysphagic throughout. Furthermore, changes seen in the damaged hemisphere in any of the groups of patients were not significant. These observations imply that over a period of weeks or months, the recovery of swallowing

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after stroke may be reliant on compensatory strategies of cortical reorganisation, through neuroplastic changes, mainly observed in the undamaged hemisphere. The implication is that new technologies that might help drive or accelerate these "natural" recovery processes for swallowing could form the basis for how rehabilitation is delivered.

NEWER APPROACHES TO DYSPHAGIA REHABILITATION

A number of different neuroimaging and neurostimulation technologies have been applied to the study of the human cerebral control of swallowing and have led to newer concepts in dysphagia management. These have included testing the effects of different techniques for experimentally manipulating cortical reorganisational mechanisms for potential therapeutic benefit. Many of these studies show promising data, however clinical trials have proven challenging, with sample sizes being small and as a result none of these modalities are currently recommended for clinical use[15]. Described below are several techniques that are being increasingly used both in research and in the clinic.

Air-pulse stimulation

As the name suggests, this technique involves delivering short pulses of air to the oropharynx in order to facilitate swallowing[16-19]. Pulses of air are delivered to the peritonsilar region using a custom-made dental splint housing tubing connected to a sphygmomanometer bulb that is manually operated by an experimenter. To date, only a handful of small studies have been conducted in healthy subjects but have shown some success. Stimulation is postulated to (mechanically) activate the pharyngeal nerve plexus to augment sensory input and engage both the brainstem and cerebral control centres during volitional swallowing. Compared to electrical stimulation, air pulse stimulation is claimed to be a natural stimulus. A recent functional brain imaging study by Soros and colleagues (2008) in healthy participants also demonstrated that bilateral peritonsilar air-pulse stimulation was associated with activation of a bilateral network of brain regions also commonly activated during tongue movement, mastication, and swallowing[18]. However, this is unsurprising since, as the authors also report, in the vast majority of events, swallowing immediately followed air pulse stimulation. Moreover, due to inter-individual anatomical differences in the dental splints and strength of the manually delivered air pulses (via the bulb), the quality of stimulation between individuals cannot be guaranteed. With further refinement of the technique and more research trials with larger sample sizes, air pulse stimulation may have a role as an adjunctive treatment for dysphagia.

Acupuncture

In traditional Chinese medicine, acupuncture therapy has been widely used to treat stroke and its complications, with some reports suggesting its use in China for over 3000 years. It is said to be easy, safe and economic as a therapy. Treatment of swallowing disorders after stroke with acupuncture is also common practice as evidenced more recently, through an increased number of research studies investigating its effectiveness[20-25]. A form of complimentary or alternative medicine, acupuncture (including electro-acupuncture and moxibustion) involves the use of fine needles to stimulate defined acupoints within the body in order to regulate the flow of Qi (energy). The mechanism of action remains poorly understood, however, acupuncture is believed to cause a variety of biological effects (including the generation of new synaptic connections and restoration of swallowing reflexes) local to the stimulation site and remotely through the conductance of Qi through its correct paths[22,24]. Despite claims of significantly better therapeutic outcomes in dysphagic patients treated with acupuncture, systematic reviews of the evidence have all proved inconclusive[23,24] with small sample sizes, poor methodology and intervention bias reported as the main areas of concern. Acupuncture may have a role in the treatment of dysphagia after stroke, however a greater number of research trials with greater patient numbers, multiple-centres and sound methodology are still required.

Transcranial brain stimulation

Transcranial magnetic stimulation: Transcranial magnetic stimulation (TMS) is a safe and non-invasive technique capable of providing information about the neurophysiological properties of a target system and has been used successfully to study swallowing[26]. TMS is based on the principles of electromagnetic induction; briefly, a rapidly changing electric current in the stimulation coil generates magnetic flux, which in turn induces electric currents within the underlying conductor such as brain tissue. Since its advent in 1985, the rapid expansion of this technique has led to the development of newer devices that are now able to deliver repetitive trains of TMS (rTMS), thereby opening up new perspectives for the use of magnetic stimulation not only for functional assessment purposes but also for treatment (or brain conditioning). As such, rTMS has been applied to the study of many brain disorders[27] such as Stroke[28], Parkinson's and other movement disorders[29], epilepsy[30-31] and depression[32-33]; as well as research into the neural mechanisms of vision[34] and language[35]. Based on this ability to change (condition) brain excitability, the use of rTMS has been proposed as a potential treatment for various disorders with putatively altered levels of activity in cortical circuits (including stroke). The development of rTMS has also allowed the imbalance of neural activity between hemispheres to be modulated in order to speed up recovery after stroke[36]. Both ipsilesional high frequency and contralesional low frequency rTMS have been shown to generate beneficial effects in the acute and chronic stroke brain[34]. However, the optimum timing, frequency, number of sessions, intensity of stimulation, anatomical area of stimulation guided by neuroimaging techniques and neuronavigation systems are still areas of expanding research.

With respects to swallowing, the pharyngeal motor cortex appears to be specifically responsive to 5Hz rTMS. When 100 pulses of rTMS are given over the cortex at 80% of pharyngeal threshold (capped at 120% of thenar threshold to comply with safety guidelines), there is increased excitability of the corticobulbar projection to the pharynx, which lasts for over 1 hour[37]. More recently, Jefferson *et al*[38], applied differing trains of 5 Hz rTMS to pharyngeal motor cortex, ranging from 100 to 1000 pulses. This work found that 250 pulses at low threshold intensities were as effective as longer or stronger 5 Hz rTMS trains at inducing plasticity in the swallowing motor system. Conversely, Mistry *et al*[39] have shown that by using an inhibitory 1Hz rTMS paradigm for 10 minutes (600 magnetic stimulation pulses) at the 120% of pharyngeal threshold, it is possible to generate a unilateral virtual lesion in the pharyngeal motor cortex that affects swallowing neurophysiology for up to 45 minutes and can also interfere with swallowing behaviour, as measured using reaction time swallowing tasks. This is of particular interest as translating neurostimulation therapies into patients with stroke is extremely challenging, because stroke is heterogeneous, often with intercurrent illness, and there are commonly problems with gaining consent. With the ability to generate virtual lesions in swallowing

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motor areas, we now have the opportunity to study function and recovery in a more controlled environment. Of importance, with the use of virtual lesions, we now have a potentially exciting model on which to test the efficacy of new neurostimulation techniques before progressing to trials in patient populations. Of relevance, Jefferson *et al*[38], were recently able to reverse the neurophysiological and behavioural effects of a virtual lesion to the inhibited pharyngeal motor cortex with contralateral 5 Hz rTMS, laying the foundation for the application of this technique in dysphagic stroke patients.

In more recent literature, the use of rTMS has been explored in the treatment of dysphagia after stroke by several authors[40-42]. In the first study by Khedr *et al*[40], excitatory 3 Hz rTMS (300 pulses at 120% first dorsal interosseous motor threshold) was delivered for 10 minutes per day for 5 consecutive days to 26 unilateral hemispheric stroke patients with swallowing problems. Stimulation was delivered to the affected hemisphere, and according to the authors, resulted in a bilateral increase in brain excitability, 1 and 2 months after treatment, with an associated improvement in the symptoms and signs of dysphagia. However, the behavioural swallowing assessment was not standardized and contained little information regarding the patients' dysphagic problems. This is an important parameter, since the authors applied rTMS to the oesophageal cortical area without using other motor cortical areas as a control site. The second study by Verin and Leroi[41] attempted to decrease transcallosal inhibition between mylohyoid primary motor cortices by using an inhibitory 1 Hz rTMS paradigm. The authors applied 20 minutes of 1Hz rTMS for five consecutive days to the healthy (unaffected) hemisphere of seven chronic dysphagic stroke patients (6 months post-stroke) and assessed swallowing using videofluoroscopy. The study resulted in a very modest decrease in the behavioural markers for swallowing impairment (aspiration–penetration scores) and in swallow reaction times. However there was no control arm for the study against which comparisons could be made. Additionally, this model of rehabilitation has only been tested in healthy volunteers for changes in cortical excitability of hand musculature and hand function after stroke but has not been trialled for swallowing musculature; therefore its feasibility is somewhat questionable.

Identifying patients suitable for rTMS based on individual patterns of cortical activation may help to implement rTMS in motor rehabilitation after stroke. Delivery of rTMS can enhance skill training when applied to the motor cortex and can transiently improve motor function when applied to the affected hemisphere of a subject with unilateral stroke[43]. Some authors are of the opinion that if used in combination with conventional therapy, rTMS might improve re-learning of movements that produce lasting changes in the organization of cortical motor outputs for at least one year after the intervention[44]. Nevertheless, the technique still requires further refinement in order to become a tool that can be used routinely in the clinical setting but application of the technique demonstrates the potential of neurostimulation in the modification of behaviour many months after cerebral injury[45].

Transcranial direct current stimulation: Transcranial direct current stimulation (tDCS) is a neurorehabilitation technique in which a weak electric current (approximately 1-2 mA) is passed over the brain. The effects are dependent on the combination of parameters such as the current strength, duration of stimulation and electrode montage[46]. It appears to be both safe and well tolerated. Transcranial DCS can alter brain excitability with further behavioural effects depending on the site of stimulation in stroke patients[47]. As for the translational aspect of this neurostimulation technique, tDCS offers some advantages, if used in the clinical setting, since the equipment needed is small and portable.

As with TMS, the effects of tDCS have been also investigated in the dysphagic stroke population, but again the results are inconclusive when all studies are taken together. Although as previously, studies in healthy swallowing have been conducted in the past[48], researchers have used different neurostimulation parameters for their studies in patients, without clear rationale for the dosage of the neurostimulation approach. A single-blinded RCT with 20 stroke patients randomised to either anodal stimulation of the ipsilesional or sham stimulation showed beneficial functional outcomes, when used as an adjunct to traditional swallowing therapy[49]. The parameters in this trial were again different to the parameters used in earlier case-controlled studies in patients (i.e. affected vs. unaffected[50,51]). Therefore, no direct conclusions can be reported for the utilisation of this technique; however results look promising and we are looking forward for some additional results for the optimal dosage and parameters, alongside the correct electrode placement over the cortex.

ELECTRICAL STIMULATION AS A REHABILITATION STRATEGY

Electrical stimulation (in general) can be described as an application of a defined current impulse to tissues (e.g. to the muscle or a tissue area) for activation of a muscle, the change of tonus of a muscle group or the excitation of sensitive areas. It is possible to distinguish between different types of electrical stimulation, which are commonly designated motor [neuromuscular electrical stimulation (NMES)] or sensory stimulation [transcutaneous electrical stimulation (TCES)].

Motor stimulation for the treatment of dysphagia

The common goal of the following modalities is reduction or prevention of aspiration in dysphagic patients.

Neuromuscular electrical stimulation (NMES): NMES has now been utilised by physical therapists for several decades and is reported to be used to treat Bell's Palsy[52], Opercular Syndrome[53], Multiple Sclerosis[54], head and neck cancer[55] and voice disorders[56], as well as stroke[57]. It allows bypass of the injured central circuitry to activate neural tissue and contract muscles to provide function to an otherwise non-functioning limb or structure. NMES involves passing a small electrical current via electrodes at supramotor thresholds to stimulate the neuromuscular junction and create a muscle contraction. It is only a viable therapeutic technique for muscles with an intact nerve supply, and has been used successfully on large skeletal muscles in diverse aetiologies, including stroke[57]. NMES, for muscle strengthening, is typically administered transcutaneously (surface) or intramuscularly. Transcutaneous NMES is applied via surface electrodes with electrical currents travelling through cutaneous tissues to the motoneurons. Intramuscular NMES on the other hand, is typically applied via hook wire electrodes inserted directly into a muscle or through electrodes permanently implanted into the muscle and therefore can evoke a more localized muscle response when compared with those elicited via surface stimulation. However, the clinical application of NMES to the swallowing musculature almost exclusively utilizes surface stimulation, whereas intramuscular NMES is limited to research contexts[58,59].

The electrical current administered during NMES changes the ionic composition of the neural, and subsequently, muscle cell membrane, triggering transmission of a motor unit action potential with a consequent motor response. Conduction of the action potential and the associated chemical synaptic transmission created by the electrical stimulation involves the same processes of neurosecretion

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and chemoreception as witnessed during a naturally occurring excitation. However, it differs from physiologic muscle activity in the order of muscle fibres recruited, the synchronicity of individual motor units, and the intensity of stimuli required for producing these changes. During volitional (i.e. physiologic) muscle activity, type I motor units (i.e. slow-twitch muscle fibres) are recruited first, whilst type II motor units (i.e. fast-twitch muscle fibres) are recruited only when additional effort is required. However, because motor unit recruitment during NMES is in an opposite manner to normal physiologic muscle activity, potential gains in strength may not necessarily carry over to any functional activities, which are important distinctions to account for when considering the complex patterned motor event of pharyngeal swallowing[59,60].

For the treatment of swallowing disorders, NMES involves applying electrodes to the muscles of the head and neck, and stimulating those muscles that are weakened or hemiparetic. Stimulation is generally combined with the subject swallowing food or fluids that are predetermined to represent the most appropriate consistency that the person can tolerate without aspiration[57,61]. Recently, Lim *et al*[62] (2009) reported that use of NMES in combination with thermal-tactile stimulation is a better treatment for patients with swallowing disorders after stroke than thermal-tactile stimulation alone.

A review of the literature for the use of intramuscular electrical stimulation (IMES), shows that it has been applied to laryngeal areas for the treatment of dysphagia[63]. Hyolaryngeal elevation is essential for airway protection during swallowing and is mainly a reflexive response to oropharyngeal sensory stimulation. Targeted IMES can elevate the resting larynx and, if applied during swallowing, may improve airway protection in dysphagic patients with inadequate hyolaryngeal motion. However, to be beneficial, patients must learn to synchronize the functional electrical stimulation with their reflexive swallowing and not adapt to functional electrical stimulation by reducing the amplitude or duration of their own muscle activity. While healthy volunteers can quickly learn this behaviour and synchronize a manual trigger with the pharyngeal phase of swallowing, its application in patients with chronic swallowing disorders is not straightforward[63].

Concerning the safety aspect of NMES and Vitalstim (DJO), Humbert *et al*[64] (2006) suggested that stimulated swallows might be "less safe" than non-stimulated swallows. In addition, several cases of mild skin irritations have been reported after treatment[59]. Several authors also point out that if electrodes are placed improperly and the unit is not used with the recommended frequency, intensity, and pulse width, the application of NMES may cause laryngeal or pharyngeal spasm[59,60]. However, Langdon *et al*[57](2010) stated that no such adverse events have been reported in public databases. Further limitations for applying NMES have also been documented: the method cannot be applied in patients who talk continuously (as may be the case with some severely demented patients), have problems getting shaved in regard to use of surface electrodes, and where a patient's co-operation in opening the mouth and in following verbal commands[65] is required, NMES treatment cannot be applied. For a recent review of NMES and TCES for swallowing rehabilitation, we also refer the reader to Humbert *et al*[66] (2012).

Transcutaneous electrical stimulation (TCES): Transcutaneous electrical stimulation (TCES) is typically delivered via surface electrodes (especially in the clinical context). The most commonly used protocol involves application of sub-motor threshold stimulation in short electrical trains (5s every minute at a frequency of 80 Hz at below motor thresholds) for 1 hour per day for up to several weeks[58]. Since the mechanism of action for TCES has not yet been elucidated, and while a direct peripheral effect has not been demonstrated, a central effect is suspected for restoring normal swallowing in post-stroke dysphagic patients[58].

With regard to the application of TCES in dysphagia therapy, the majority of published studies have utilised the VitalStim unit, which was approved in 2001 by the Food and Drug Administration of America, specifically for use in dysphagia rehabilitation. VitalStim can be used at both supra and sub motor thresholds, so can be used for both NMES and TCES, but in this review, we focus on the TCES usage. Although VitalStim has been utilised by several thousand certified users in the USA (according to Langdon (2010) without reports of adverse effects), expert critical appraisals[57,59,64], have shed light on inconsistencies in the significance of treatment success, thereby presenting conflicting or inconclusive evidence for its efficacy in improving swallowing function post-stroke. The major points of contention in the published studies include small numbers of patients and significant methodological flaws: studies had been conducted on subjects with normal swallow function, inconsistent electrode placements, and use of participants of a much younger age than the populations who experience the highest prevalence of dysphagia etc. Nevertheless, regional (advocates) argue that there is a good theoretical basis to support the use of TCES as an adjunctive therapy in dysphagia[57,58,64].

Oh *et al*[67](2007) have suggested that multiple sessions of TCES on the neck muscles might help to improve swallowing function in dysphagic patients (early after stroke), and that this improvement might be related to long-term cortical reorganization. Bipolar surface electrode placements overlying the submental and laryngeal regions were tested as to their effect on laryngeal and hyoid elevation in healthy subjects. However, there is indication that the method could be useful in treatment of dysphagic patients as well. Permsirivanich *et al*[68](2009) reported that TCES is superior to a number of compensatory methods in the treatment of dysphagia. Freed *et al*[65]. could demonstrate that final swallow scores after VitalStim treatment in patients with dysphagia were higher than those following thermal-tactile stimulation, although this study used levels at both supra and sub motor threshold. A recent uncontrolled study by Gallas *et al*[69](2010) also demonstrated that swallowing dysfunction in the oral phase (none of the patients were on non-oral feeding) could be improved using TCES during swallowing. However, several authors referred that TCES is rapidly gaining popularity with clinicians as a treatment modality for individuals with pharyngeal dysphagia despite reports of the absence of positive effects when blinded and when more objective measures such as myoelectric activity, hyoid movement or biomechanics were defined as outcome measures[59,60,70]. These authors also suggested several reasons why efficacy of the TCES device could not be demonstrated: (1) the frequency at which electrical stimulation was delivered might not always have been optimal in order to recruit motor units involved in swallowing; (2) according to motor learning principles, in order to be effective, an exercise program must match closely the target behaviour; (3) subjects were expected to exhibit myoelectric changes without any additional exercise[60]. Furthermore, there are indications that TCES gives better results when associated with swallowing[58].

Interferential electric stimulation: Another common form of sensorimotor transcutaneous stimulation from the physical therapy realm is interferential electrical stimulation (IFS) which has been investigated, with mixed results, as a technique to reduce pain,

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improve range of motion, or promote local healing following various tissue injuries[71-75]. Surface electrodes are placed surrounding the affected area but unlike NMES, IFS uses alternating medium-frequency current (4,000 Hz) amplitude modulated at low frequency (0-250 Hz)[73] that is believed to permeate the tissues more effectively and, with less unwanted stimulation of cutaneous nerves, is reported to be more comfortable than NMES. Parameters for modulation include the frequency of stimulation, the pulse duration, treatment time, and electrode-placement technique; however no standardized protocols currently exist. The mechanism of action for IFS is still unknown but several theoretical physiological mechanisms for its analgesic effects have been presented in the literature. These include the "gate control" theory, increased circulation, descending pain suppression, block of nerve conduction and the placebo effect[73]. For the treatment of swallowing disorders, a recent study by Furuta *et al*[72](2012) in 10 healthy adult males, showed that IFS (at sensory thresholds of 2-3 mA) to the submandibular region of the neck, increased the number of observed swallows during a 15 minute stimulation period, postulating a possible facilitation of the swallowing reflex arc through summation and modulation of superior laryngeal nerve signals. They further suggest that IFS could be used as an alternative stimulation mode for treating pharyngeal dysphagia because of the added level of comfort when compared to more traditional pulsed current therapies (i.e. NMES). However, the authors warn that increasing the stimulation threshold to motor levels could lead to laryngospasms and compromise airway safety similar to NMES as shown by Ludlow *et al*[76].

Additional forms of stimulation for the treatment of dysphagia

For more than a decade now, there has been a great deal of interest focusing on the interaction between sensory input and motor output. Studies, conducted both in animals and humans, have demonstrated that alterations in sensory input such as amputation, nerve transection, peripheral nerve stimulation and skill acquisition can influence motor cortical excitability and organisation[77]. It is now well established that sensory input is crucial to the initiation and modulation of normal swallowing; this perhaps being best demonstrated by studies using surface anaesthesia of the oropharynx that produce swallowing difficulties in healthy human subjects[78-81]. Moreover, reports in the literature by Hamdy *et al*[82,83](1998) demonstrate that alterations in sensory input to the swallowing system can result in changes in excitability within the corticobulbar pathways. For example, cranial nerve stimulation can facilitate pharyngeal motor evoked potentials evoked by TMS of the human pharyngeal motor cortex[82]. Furthermore, short trains of sensorimotor stimulation applied to the pharynx results in long-lasting increases in pharyngeal motor cortex excitability as measured by TMS[83].

Palatal electrical stimulation: Stimulation of the palate using a customised training appliance has also demonstrated beneficial results in some patients[45,84]. However, each patient requires individual consideration and is necessitated to wear the custom-built palatal device continuously in order to achieve effective results. Of note however, during testing in chronic patients, Selley *et al*(1985) recommend patients also choose well-flavoured foods, cold sweets and iced drinks helps to improve swallowing performance. Since these individual factors may also influence swallowing performance alone, interpretation of the results, and therefore the effectiveness of the training appliance, becomes more difficult.

Pharyngeal electrical stimulation (PES): The application of PES in the treatment of swallowing impairments has been developed extensively over the last 15 years by Hamdy and colleagues[1,13,14,78,83,85] through trials in both in healthy participants and stroke patients with dysphagia. These data show that PES is capable of increasing corticobulbar pathway excitability, without affecting brainstem responses[78,85], increases brain activity, assessed through blood-oxygenation level-dependent functional magnetic resonance imaging responses to swallowing[85] and improves levels of swallowing dysfunction after stroke for at least 30 minutes, assessed using videofluoroscopy, the gold standard method for swallowing assessment[85]. Below is a short review of this work.

PES is performed with the use of an intraluminal pharyngeal catheter through which, short trains of electrical stimuli can be delivered as a source of peripheral sensorimotor input. Such stimulation preferentially activates sensory afferents from the pharynx, and at high enough intensities, can evoke small twitches of the pharyngeal musculature. This latter element also produces additional (natural) sensory stimulation that adds to the electrically induced activity. The pharyngeal mucosa, between the auditory tubal orifice and rostral to the epiglottis, is innervated by sensory and motor fibres of the glossopharyngeal nerve, whereas fibres from the vagus (mainly the superiorlaryngeal nerve) supply the pharyngolaryngeal mucosa from the epiglottis. Since electrical stimuli activate a broad range of receptors and afferent fibres, it is likely that pharyngeal stimulation activates a mixture of these fibres, both vagal and glossopharyngeal, and that this amalgamation contributes significantly to cortical pharyngeal sensorimotor information which can be recorded as evoked potentials using surface electrodes placed over the scalp or through magnetoencephalography[86]. The main advantage that PES has over other forms of stimulation that try to replicate more natural sensory inputs (e.g. tactile faucial pillar stimulation) is that the parameters of stimulation are easily controlled and replicated across subjects[85,86]. Consequently, several reports have suggested the potential therapeutic role PES can have for the treatment of swallowing impairments after brain injury[1].

Based on these earlier observations of Fraser *et al*[78,85] on the effects of PES on corticobulbar pathways and swallowing function, Jayasekeran and colleagues[87] sought to substantiate the mechanisms by which PES can help reverse both cortical and behavioural swallowing impairments in dysphagic stroke patients. Using the virtual lesion model of swallowing impairment developed by Mistry *et al*[39], the authors studied the effects of active and sham PES on both swallowing neurophysiology and behaviour after inducing a virtual lesion in healthy volunteers. They were able to show strong reversal of the neurophysiological and behavioural effects of a virtual lesion to the inhibited pharyngeal motor cortex with PES, laying the foundation for the application of this technique in dysphagic stroke patients.

Moving forward, Jayasekeran and colleagues[88] refined the treatment parameters in a dose-response study of PES in dysphagic stroke patients and assessed swallowing outcomes, again using videofluoroscopy. They found that a stimulation regime of PES once a day for 3 days was the most practical and effective course of neurostimulation required to reduce aspiration. In addition, when the efficacy of PES was evaluated in a randomised clinical trial of 28 acute dysphagic stroke patients, the authors concluded that PES significantly improved swallowing performance and intriguingly reduced hospital stay, when compared to the control group. In addition, one of the most recent reports by Langdon (2011), emphasises the importance of PES as the 'most promising and exciting technique' for the therapeutic treatment of dysphagic patients. Moreover, it points out that this modality of electrical

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stimulation is very well tolerated by the research subjects[88].

CONCLUSIONS

Advances in the field of neurorehabilitation of motor systems in general, have led to a wide range of approaches and are currently under rigorous investigations. Our field of dysphagia neurorehabilitation is sharing some of the formulated hypotheses and concepts for functional rehabilitation with neurostimulation. Importantly, the newest results from studies looking into the cortical and subcortical control of human swallowing have helped to guide, based on the increased knowledge that peripheral and central inputs, experimental paradigms targeting swallowing neural reorganization which are moving prior from the laboratory into clinical practice for dysphagia rehabilitation.

CONFLICT OF INTERESTS

There are no conflicts of interest with regard to the present study.

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