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Original article

Effect of submental sensitive transcutaneous electrical stimulation on virtual lesions of the oropharyngeal cortex

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ABSTRACT

Objective: The aim of this study was to assess the effect of submental sensitive transcutaneous electrical stimulation (SSTES) on pharyngeal cortical representation after the creation of an oropharyngeal cortical virtual lesion in healthy subjects.

Methods: Motor-evoked potential amplitude of the mylohyoid muscles was measured with transcranial magnetic stimulation (TMS), the oropharyngeal cortex was mapped by cartography, and videofluoroscopic parameters of swallowing function were measured before and after SSTES (at the end of SSTES [0 min] and at 30 and 60 min), after the creation of a cortical virtual lesion (repetitive TMS, 1 Hz, 20 min on the dominant swallowing hemisphere).

Results: Nine subjects completed the study. After 20 min of SSTES, motor-evoked potential amplitude increased ($P < 0.05$), as did swallow reaction time after repetitive TMS, as seen on videofluoroscopy, which was reversed after electrical stimulation. On cortical mapping, the number of points with a cortical response increased in the dominant lesioned hemisphere ($P < 0.05$), remaining constant at 60 min ($P < 0.05$).

Conclusion: SSTES may be effective for producing cortical plasticity for mylohyoid muscles and reverses oropharyngeal cortical inhibition in healthy subjects. It could be a simple non-invasive way to treat post-stroke dysphagia.

1. Introduction

Oropharyngeal dysphagia is common after acute hemispheric stroke, affecting about half of the patients within 24 hr [1]. Although most dysphagic patients show natural recovery within the first month, 30% to 40% never experience complete recovery [2] and are at risk of aspirations, which increases the risk of post-stroke pneumonia [3]. These dysphagic patients generally present severe stroke, and outcomes tend to be worse in terms of residual impairments, activity limitations [4] and death, along with high levels of institutionalization [5]. Traditionally, reeducation and adaptation are based on fluid and food texture modification, enteral feeding, oral care, speech language therapy and stimulation techniques [6,7].

Improving post-stroke dysphagia with neurorehabilitative treatments by non-invasive cortical stimulation and brain stimulation is a new desired goal [8]. Transcranial magnetic stimulation (TMS) is a well-tolerated procedure that modulates cortical excitability. Depending on stimulation parameters, TMS can upregulate or downregulate excitability to different extents in the neural structures under the stimulating coil [9]. Both techniques can effectively modulate brain function and are painless and non-invasive. The technique has been used with efficacy in post-stroke patients, so cortical neuromodulation could be effective for post-stroke dysphagia [10].

Another method for cortical neuromodulation is peripheral electrical stimulation, studied for oropharyngeal dysphagia for a

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few years and found efficient. Actually, 2 techniques have been developed. The first is endopharyngeal electrical stimulation, and its efficacy has recently been demonstrated. The technique decreases aspiration and penetration, improves feeding status and seems to shorten the length of hospital stay [11]. It increases motor pharynx cortex activity and area representation, both in healthy subjects [12] and stroke patients [13]. Another approach involves peripheral electrical stimulation, used in physiotherapy. Transcutaneous electrical nerve stimulation (TENS) has been used for more than 10 years and found to improve motor function in stroke. It has also been used to treat post-stroke dysphagia and appears to be safe and effective [14]. It is widely used in North America and seems to give better results when associated with swallowing [15,16]. The mechanisms of action have not been elucidated, and although a direct peripheral effect has not been demonstrated, a central effect is suspected.

From concepts of long-term reorganization of the human cortex driven by sensory stimulation, we tested whether submental sensitive transcutaneous electrical stimulation (SSTES) could modify oropharyngeal cortical representation in healthy subjects after the creation of a cortical virtual lesion by using low-frequency repetitive TMS.

2. Methods

2.1. Participants

Ten healthy subjects (7 men, mean age: 30 ± 5 years) volunteered to participate. Exclusion criteria were the presence of pre-existing swallowing disorder, psychiatric disease, epilepsy, neurosurgical surgery, digestive disease, implanted pacemaker or intracorporal stimulator, the use of cannabis (and other drugs) or therapeutics modifying cortical excitability, or chronic respiratory, neurologic or otolaryngology diseases that could affect swallowing. None of the women were pregnant. The experiments were approved by the local research ethics committee (*Comité de protection des personnes Nord Ouest 4*, France) and were performed in accordance with the Declaration of Helsinki.

The study was conducted at Rouen university hospital. Each subject had to be available for 2 sessions: first, for a cerebral MRI and then the study protocol. We first used cerebral imaging to map the oropharyngeal cortex by using TMS. Thereafter, we created a virtual lesion of this oropharyngeal cortex by using repetitive TMS (rTMS) and studied the effect of TENS on this lesion.

2.2. Material

2.2.1. MRI

All subjects underwent cerebral MRI before the experiment to verify the absence of intracerebral disease and images were used for neuronavigation. T1-weighted MRI cerebral images were acquired on an MRI 3 T (General Electric, Discovery MR750, Milwaukee, WI).

2.2.2. Neuronavigation

Neuronavigation is a frameless stereotaxic system used in real-time that integrates high-resolution structural T1-weighted MRI slices to create a 3D reconstruction of the head and brain anatomy. An infra-red camera system detected reflectors mounted on the subject's head and fixed to the magnetic coil. A referencing procedure with cranial landmarks was first performed to co-register the head and the coil in the coordinate system of the brain MRI. When this co-registration was achieved, the system allowed for the visualization of the location and orientation of the coil over the head as well as the resulting electric field density within the cortex in real time on a computer screen with eXimia NBS software (Nexstim, Helsinki, Finland). This technique allowed for recording by MRI all the stimulation locations and especially the best points for each hemisphere. Therefore, this system allowed the subjects to move for swallowing evaluation by videofluoroscopy.

2.2.3. TMS

All stimulations involved use of a Magstim Super Rapid stimulator (Magstim, Whitland, UK) equipped with an air-cooled, double, 70-mm, figure-eight coil (maximal peak magnetic field, 2.0 Tesla). To identify the sites of cortical stimulation, an 11×5 grid with rows set 1.6-cm apart anterioposteriorly and mediolaterally was drawn on a surgical cap attached to the subject's scalp with use of tape. The vertex of the cranium was first identified. The grid was then positioned with the rows perpendicular to the mediosagittal or lateral plan. The coil was then laterally positioned to obtain the largest electromyography (EMG) mylohyoid motor-evoked potential (mMEP) response on each hemisphere. Once these areas were located, the motor threshold was searched. To identify the motor threshold value, cortical stimulation intensity was reduced in 10% increments until the stimulation evoked an mMEP response $< 50\ \mu V$ in at least 2 of 4 consecutive trials. The hemisphere with the largest mMEP response and the lowest motor threshold was termed the lesioned hemisphere (LH), and the contralateral hemisphere (with smaller mMEP) the non-lesioned hemisphere (nLH). Then, 3 stimulations were repeated on each grid point at 20% intensity above the motor threshold to create the oropharyngeal cortical mapping of each hemisphere. The stimulations were not performed during swallowing (monitored by continuous EMG) to avoid cortical potentiation.

2.2.4. rTMS

The same stimulator was used for rTMS to obtain a virtual cortical lesion. The coil was placed on the best point of the LH. Stimulation was performed at 1 Hz for 20 min at 120% of the LH's motor threshold, limited to a maximum of 100% of the stimulator's output as previously described for the oropharyngeal motor cortex [10].

2.2.5. EMG

MEPs in response to TMS were recorded from the mylohyoid muscles [17] with a pair of silver-silver chloride surface electrodes (EL258RTa) placed on each side of the subject's submental muscles [18]. Electrodes were connected to an EMG recording system (EMG 100Ca, BIOPAC System, Goleta, CA), with the following settings: filters 2 to 5 kHz, frequency 20 kHz and sweep length 1 sec.

2.2.6. Swallowing evaluation

Swallowing function was evaluated by using a standardized videofluoroscopic barium swallow [19]. Only lateral projection fluoroscopic images were acquired with use of a radio amplifier (Flexiview 8800, General Electric, United Medical Technologies, Fort Myers, FL) and recorded on a computer at 20 frames/sec for later analysis (MMS, Tubingen, The Netherlands). The anterior incisors, superior hard palate, posterior cervical spine and inferior proximal esophagus were included in the field of the lateral projection. Subjects were comfortably seated in a chair and were told not to move during the video recording. They were then asked to swallow three 10-ml boluses of high-density liquid consistency barium suspension (barium at 50%) from a cup. The procedure was stopped as soon as aspiration occurred.

Bolus transit measurements included oral transit time (OTT), the interval between the first frame showing tongue tip elevation and the first frame showing the arrival of the head of the bolus at the ramus of the mandible; swallowing response time (SRT), the delay between the oral and pharyngeal phases of swallowing, that