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Non-invasive cerebral stimulation for the upper limb rehabilitation after stroke: A review

Stimulations cérébrales non invasives et rééducation du membre supérieur dans l'hémiplégie vasculaire : revue et perspectives

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Abstract

Numerous studies have recently been published on improving upper-limb motor function after stroke. There has been a particular interest in brain stimulation techniques, which could promote brain plasticity. In this review, transcranial Direct Current Stimulation (tDCS) and repetitive Transcranial Magnetic Stimulation (rTMS) are presented as techniques that could be relevant in Physical Medicine and Rehabilitation (PM&R) centers in the future. We are presenting a comprehensive literature review on the studies using tDCS or rTMS for upper-limb rehabilitation after a stroke. Both techniques have shown their ability to modify cortical excitability and to transitorily improve upper-limb function after one single stimulation session. The first placebo-controlled, blinded therapeutic trials, which included repeated daily sessions, seem quite promising, and deserve to be validated by further trials.

Keywords: Stroke; Paresis; Cerebral stimulation; tDCS; rTMS; Rehabilitation

Résumé

L'amélioration fonctionnelle du membre supérieur de l'hémiplégique suite à un accident vasculaire cérébral (AVC) est l'objet de nombreux travaux et reste un enjeu majeur de la rééducation, avec des résultats encore décevants. Parmi les techniques récemment proposées, émergent les techniques de stimulation cérébrale, dont l'objectif serait d'orienter la plasticité cérébrale. Dans cet article, deux techniques de stimulation cérébrale non invasives, la stimulation transcrânienne par courant continu (*transcranial Direct Current Stimulation* [tDCS]) et la stimulation magnétique transcrânienne répétitive (*repetitive Transcranial Magnetic Stimulation* [rTMS]), sont présentées ; elles pourraient, à terme, être utilisées de manière courante dans cette déficience. Une revue exhaustive de la littérature proposant d'utiliser tDCS et rTMS chez des patients présentant une atteinte motrice du membre supérieur consécutive à un AVC est réalisée. D'un point de vue fondamental, la capacité de ces deux techniques à moduler l'excitabilité du cortex cérébral et à améliorer, au moins de manière transitoire, la fonction du membre supérieur, semble validée pour une session unique de stimulation. Les résultats des premiers essais thérapeutiques, en aveugle et contre placebo, proposant des sessions répétées et quotidiennes, semblent prometteurs, et méritent d'être confirmés par de nouveaux essais.

Mots clés : Accident vasculaire cérébral (AVC) ; Hémiplégie ; Hémiparésie ; Stimulation cérébrale ; tDCS ; rTMS ; Rééducation

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1. English version

1.1. Introduction

Optimizing the care management of stroke patients is a national priority. Stroke prevalence is estimated at 400,000 persons in France. It is the third leading cause of death in men and the second in women. Furthermore, it is the first cause of acquired disability. More than 50% of stroke patients retain severe neurological impairments, most often affecting motor function [34,35]. Among these patients, about 80% will retain some grasping deficits linked to upper limb impairments.

Improving upper limb function has become a major challenge for PM&R teams; however, the results remain disappointing [68]. In daily practice, the principles of upper limb rehabilitation are largely based on the PM&R techniques that emerged in the middle of the 20th century [15,89]. However, major conceptual developments were recently developed [89], emerging from fundamental neuroscience that evidenced brain plasticity with brain imaging techniques. The concepts of learning and of task-oriented rehabilitation have become essential [33]. The concepts of learned non-use (initially described by Meige [58]) and of interhemispheric competition [30] are nowadays more readily admitted [68]. Newly proposed rehabilitation strategies therefore focus on restoring the balance between the two hemispheres in favor of the affected one.

Invasive or non-invasive brain stimulations have the capacity to modulate cortical excitability and to optimize brain plasticity. These techniques have already largely been studied in psychiatry [79] and pain management [21,47]. In post-stroke rehabilitation, interesting results have been reported for improving phasic disorders [61,90], neglect syndrome [9] and swallowing disorders [38]. However, the use of these treatments still remains to be defined in clinical practice. Transcranial Direct Current Stimulation (tDCS), repetitive Transcranial Magnetic Stimulation (rTMS) and Paired-Associative Stimulation (PAS) [8] are non-invasive techniques. Invasive stimulations (implanted epidural electrodes) have been tested in phase I, II and III clinical trials, with quite inconclusive results [73].

The objective of this article is to describe tDCS and rTMS: these two techniques may be used in neurological rehabilitation in the future. We will also present a literature review on their application for upper limb rehabilitation after stroke.

1.2. Brain stimulation techniques

1.2.1. Transcranial Direct Current Stimulation

1.2.1.1. Overview. The therapeutic use of electrical currents through the scalp has been proposed since the ancient times (writings describing the use of torpedo fish for relieving headaches in authors such as Scribonius Largus, Claudius Galenus, and Pliny the Elder). In the 11th century, the Arab physician Ibn Sidah used this technique to treat epileptic seizures [36,75]. After the works of Walsh on torpedo fish [86], the beginnings of electrophysiology were reported by the Italian physicists Galvani and Volta who described the physiological effects induced by electrical currents [23,24,84,85]. Some years later, Giovanni Aldini [1] proposed to use galvanic currents for treating mental disorders [52].

With the recent development of Transcranial Magnetic Stimulation (TMS), which enables to measure the cortical excitability, Priori et al. [76] could determine the current parameters (intensity, electrode position, stimulation duration) that induce an actual modulation of the primary motor cortex excitability. This has been validated and further developed by Nitsche and Paulus who drew the bases of today's stimulation paradigms [65].

1.2.1.2. Presentation. tDCS consists in applying low-intensity current between two electrodes on the scalp. The "active" electrode is placed above the part of the brain to be stimulated and the reference electrode is placed on a neutral position. Part of the current will be short-circuited by the scalp and another part will stimulate the cortex. Using non-metallic electrodes helps avoiding electrolysis reactions. Skin preparation might be useful to reduce the impedance of the skin/electrode interface. It is recommended to reach progressively the targeted stimulation intensity (generally a 10-second ramp at the beginning and at the end of the stimulation). Depending on the electrode polarity, the cerebral cortex excitability will be increased (anodal stimulation) or decreased (cathodal stimulation). The amplitude and the duration of the cortical excitability changes depend on the stimulation intensity and duration. Most published protocols have used intensities ranging from 1 to 2 mA, with stimulation duration up to 25 minutes, using 25 cm^2 to 35 cm^2 electrodes. In these circumstances, changes in corticospinal excitability last for more than one hour. A review describing the technique's state of the art was proposed by Nitsche et al. [63].

1.2.1.3. Neurophysiological effects. In an original article, Nitsche and Paulus demonstrated the possibility to modulate cortical excitability by applying tDCS [65]. The active electrode was placed over the primary motor cortex and the reference electrode was placed over the contralateral supraorbital region.

After a 4-seconds stimulation, the motor evoked potentials (MEP) amplitude was increased by about 25% after anodal stimulation and reduced by about 20% after cathodal stimulation. These changes in cortical excitability were measurable during the stimulation and also after it: this lasting effect was called "post-effect". The duration of this post-effect depended on the intensity and on the duration of the stimulation.

1.2.1.4. Mechanisms of Transcranial Direct Current Stimulation. Human applications for tDCS are relatively new, but understanding of its action mechanisms is derived from animal experiments dating back to the sixties [4].

TDCS is different from other brain stimulation techniques since it doesn't directly induce action potentials, unlike TMS and transcranial electrical stimulation (TES). Thus, it is