Synchronous Electrical Stimulation of Laryngeal Muscles: An Alternative for Enhancing Recovery of Unilateral Recurrent Laryngeal Nerve Paralysis

*,†Alejandro Garcia Perez, ‡Xochiquetzal Hernández López, ‡Víctor Manuel Valadez Jiménez, *Arturo Minor Martínez, and §Pablo Antonio Ysunza, *†‡*Mexico City, and Veracruz, Mexico* §*Royal Oak, Michigan*

Summary: Background. Although electrical stimulation of the larynx has been widely studied for treating voice disorders, its effectiveness has not been assessed under safety and comfortable conditions. This article describes design, theoretical issues, and preliminary evaluation of an innovative system for transdermal electrical stimulation of the larynx. The proposed design includes synchronization of electrical stimuli with laryngeal neuromuscular activity.

Objective. To study whether synchronous electrical stimulation of the larynx could be helpful for improving voice quality in patients with dysphonia due to unilateral recurrent laryngeal nerve paralysis (URLNP).

Materials and Methods. A 3-year prospective study was carried out at the Instituto Nacional de Rehabilitacion in the Mexico City. Ten patients were subjected to transdermal current electrical stimulation synchronized with the fundamental frequency of the vibration of the vocal folds during phonation. The stimulation was triggered during the phase of maximum glottal occlusion. A complete acoustic voice analysis was performed before and after the period of electrical stimulation.

Results. Acoustic analysis revealed significant improvements in all parameters after the stimulation period.

Conclusion. Transdermal synchronous electrical stimulation of vocal folds seems to be a safe and reliable procedure for enhancing voice quality in patients with (URLNP).

Key Words: Larynx–Electrical Stimulation–Voice–Therapy–Paralysis.

INTRODUCTION

Dysphonia, which includes hoarseness and breathiness, is defined as a decrease in voice quality and an increase in vocal effort. It is the most commonly found symptom in patients with unilateral recurrent laryngeal nerve paralysis (URLNP).[1] It has been reported that dysphonia significantly disrupts the quality of life of affected individuals.[2–4] URLNP can be the result of an injury or damage to the 10th cranial nerve or its peripheral branch (ie, the recurrent larynx nerve). The etiology of this disorder includes iatrogenic situations such as inadvertent injuries during surgery, complications from endotracheal intubation. Also, noniatrogenic causes, such as trauma involving the neck or chest, mass compression, and viral infections have been reported. Finally, drugs with potential neurotoxicity effect, such as Vincristine, have been reported as a rare etiology of vocal fold paralysis.[5]

The diagnosis of URLNP is a complex task and should be carried out by experienced clinicians. To reach an accurate diagnosis and rule out that vocal fold immobility is not derived from mechanical causes (eg, from neoplasm, arytenoid cartilage dislocation, or cricoarytenoid arthritis), it is usually necessary to combine several evaluation procedures, including external palpation of the laryngeal region, videolaryngoscopy, stroboscopic endoscopy, laryngeal electromyography (EMG), imaging, and laboratory studies.[6,7]

Once the diagnosis has been established, the management of URLNP primarily depends on its associated symptoms and recovery prognosis, which in turn depend on the severity of the paralysis, the position of the paralyzed vocal fold, and its etiology.[8–10] At present time, the two main options for treatment are voice therapy and surgical procedures. Unfortunately, few studies provide evidence supporting the efficacy of voice therapy. Moreover, the studies addressing the efficacy of voice therapy have yielded inconclusive results.[11–14] Nonetheless, it is generally accepted that, under certain conditions, voice therapy may contribute to enhance voice quality by improving glottal occlusion as a result of training the intrinsic laryngeal muscles to develop compensatory functions. However, the paralysis persists in most of the cases, and the long-term effectiveness of voice therapy has yet to be demonstrated.[15]

Surgical methods are also available for treating URLNP. In particular, phonosurgical techniques aimed to correct vibratory movements of vocal folds during phonation by correcting the vocal fold position or tension or by increasing the vocal fold volume.[16,17] Surgical options are diverse and they have been in constant development. Several studies support the effectiveness of these methods.[18–20] However, given its invasive nature, surgery also presents disadvantages such as the risk of damaging healthy structures and the need, in some cases, to be performed repeatedly.[21–23] In addition, although some surgical procedures can be reversible by removing the implants, other procedures are actually irreversible.[24]

Functional electrical stimulation (FES) is a technique that dates back to the middle of the 19th century. It uses electric currents to induce contractions in paralyzed muscles and has

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From the *Centro de Investigación y Estudios Avanzados del Instituto Politécnico Nacional, Mexico City, Mexico; †Instituto Tecnologico Superior de Poza Rica, Poza Rica, Veracruz, Mexico; ‡Servicio de Foniatría del Instituto Nacional de Rehabilitación, Mexico City, Mexico; and the §Department of Speech and Language Pathology, Ian Jackson Craniofacial Clinic, Beaumont Health System, Royal Oak, Michigan.

Address correspondence and reprint requests to Pablo Antonio Ysunza, Department of Speech and Language Pathology, Beaumont Health System, Medical Office Building, 3535 West 13 Mile Road, Suite 101, Royal Oak, MI 48073. E-mail: antonio.ysunza@beaumont.edu

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been widely studied as a therapeutic option for treating paralyzed muscles, especially distal muscles.[25,26] In many cases, FES has led to the recovery of voluntary movement of the paralyzed muscles. However, the physiological mechanism by which this occurs is still unclear.

The use of FES in the treatment of voice disorders has been studied almost since its origins. A review of the literature reveals that, despite the significant scientific interest in FES, the modern technological tools have become available, and in our improved understanding of larynx physiology, FES has not become an effective therapeutic intervention to treat dysphonia in patients with URLNP.[27–29] The main obstacles that, until now, have precluded the use of FES as an effective therapeutic technique for treating voice disorders are the great complexity of the laryngeal physiology, and the difficulty of producing sufficient neuromuscular stimulation using superficial electrodes without causing pain or skin affectations in the stimulated area.[30,31]

The purpose of this article was to study the use of an innovative system for transcutaneous electrical stimulation of the vocal folds. The device considers two theoretical issues:

The first concerns the fact that during sustained phonation, the minimum impedance through the laryngeal tissue coincides with the phase of maximum glottal occlusion in each vibratory cycle,[32] so that if the electrical stimuli are matched with such phase, the intensity of the stimuli required to produce the desired effects could be reduced.

The second issue is derived from the theory of Rushton[33] about the physiological mechanism through which electrical stimulation promotes restorative synaptic modifications that in some cases leads to the recovery of muscle functionality. This theory, based respectively on the widely studied Hebbian theory,[34] suggests that the occurrence of such neuromuscular restorative process is highly dependent on the coincidence of the electrical stimuli with the conscious, voluntary effort of the patient, and the consequent coincidence between the occurrence of dromic and antidromic impulses on Hebb-type cells. The results of the studies carried out by Ptok and Strack[35] and Lagorio et al[36] showed an increment on the efficacy of FES therapies when combined with voice exercises, which may be explained in accordance with the theory of Rushton.

The proposed stimulation system features, in particular, the synchronization of electrical stimuli with the vocal fold vibration that occurs during sustained phonation by the patient, in such a way that one current pulse is triggered and delivered to the laryngeal tissue in each cycle, making the stimulation frequency being the same as the fundamental frequency (F_0) of voice. The system uses the electrical signal of voice as synchronization source for triggering the electrical pulses, and it provides the possibility of selecting the phase of vibration of the vocal folds in which the stimuli are delivered (maximal occlusion phase). These characteristics allow the therapy with FES to take advantage of the previously described approaches by making the electrical pulses coincide with the maximum glottal occlusion and with conscious voluntary effort of the patient.

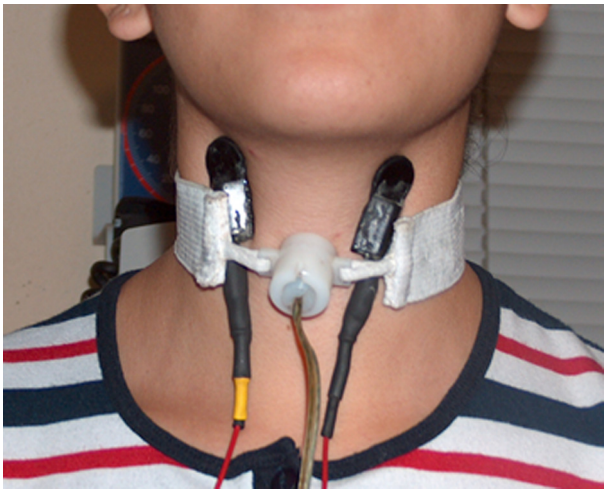

FIGURE 1. Microphone and electrodes placement.

MATERIALS AND METHODS

A synchronous electrical stimulator and a purpose-built stroboscopic light source were developed at the Centro de Estudios Avanzados (CINVESTAV) del Instituto Politecnico Nacional in Mexico City. A 3-year prospective study, approved by the Institutional Review Board of the Instituto Nacional de Rehabilitacion in Mexico City, was conducted from June 1, 2007, to June 1, 2010.

Synchronous electrical stimulator

During sustained phonation, the electrical stimulator generated, at each cycle of vocal fold movement, a square current pulse with specific parameters. To this end, the voice signal of the patient was captured through an electret-type microphone that was placed over the thyroid cartilage. The microphone was held in place by an elastic band (Figure 1). The acquired signal was then electronically filtered and conditioned to obtain a quasi-sine waveform of constant amplitude and whose frequency was the F_0 of voice of each patient (ie, the frequency corresponds to the frequency of the vibration of the vocal fold). The signal was harnessed to obtain a synchronization pulse at the zero crossing of each rising edge which was used as synchronization source for triggering the electrical stimuli through the processing of a microcontroller. The amplitude and duration of the synchronization pulses were 5 V and 140 microseconds, respectively.

The equipment features a digital user interface consisting of a screen and keyboard that allows the physician to program and visualize the stimulation parameters to be used. The same microcontroller (PIC16F877A from Microchip Technology, Inc., Chandler, AZ) controls the user interface and uses the synchronization pulses for generating stimulation pulses through an analog circuit. Carbon rubbed electrodes were used (REF 79966 - Intelect Advanced/Intelect Mobile; DJO, UK, LTD, Guilford Surrey, UK) for performing the percutaneous electrical stimulation.

The intensity of the electrical stimulus and the duration of the pulses can be adjusted from 0 to 10 mA and from 0.1 to 0.5 milliseconds. A value of 500 Hz was arbitrarily considered as the maximum F_0 of the patients for being candidates for using