CONTRALATERALLY TRIGGERED EYEBLINK FOR THE PARALYZED EYELID: STIMULATION PATTERN AND TRICKS.

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Abstract
Paralysis of the orbicularis oculi muscle, due to a facial nerve injury, may lead to a severe corneal damage up to the sight impairment. The most amazing and challenging goal of surgical techniques for the eyelid reanimation is to achieve a spontaneous, simultaneous bilateral eyeblink. An implantable device could allow it, by detecting the onset of the electrical activity of the healthy orbicularis oculi muscle and triggering the stimulation of the paralyzed muscle.

Keywords: facial paralysis, eyeblink, motor neurons dynamic sensitivity

Introduction
Facial paralysis affects up to 30 persons/100000/year in Western Europe and the States (Schrom and Bast, 2010). Besides the impairment of mimic and smile, the most severe damage is the loss of the blink reflex and the eyelid closure, with corneal exposure.

The idea of a bionic reanimation of a paralyzed hemiface is not new (Tobey and Sutton, 1978) and the feasibility of a functional electrical stimulation of a paralyzed hemiface has already been assessed (Somnia et al., 2001; Kurita et al., 2010).

We are projecting a closed-loop device (Fig. 1) detecting the onset of the EMG activity of the healthy orbicularis oculi muscle and triggering the stimulation of the contralateral (paralyzed) one, with a dynamic pattern.

Material and Methods
Natural eyeblink kinematics
10 healthy subjects were studied (6 females, 4 men, age 21-56 yo, mean 33,5 yo). They were asked to look ahead for 1 minute. Their blink frequency, speed and duration were recorded by taping a microaccelerometer (less than 0.5 g weight) onto the left upper eyelid.

Fig. 1: Project of a closed-loop implantable device detecting the onset of the EMG activity of the right (healthy) orbicularis oculi muscle and triggering the stimulation of the contralateral (paralyzed) one, with a dynamic pattern.

EMG onset recording
Surface EMG electrodes were placed on the right orbicularis oculi, as well as masseter and temporalis muscles. Orbicularis oculi activity was used as a trigger for the stimulation of the contralateral facial nerve branch, controlling the eyelid movement.

Stimulation pattern
A dedicated Labview software was build up to read the trigger signal and deliver a pattern of stimulation, i.e. a train of 10 pulses (pulse width 0.8 ms) at a constant carrier frequency (range 20-250 Hz), in which the interval between the first and second pulse was adjustable in length (dynamic
pulse, range 250-300 Hz) thus conferring the lid movement natural speed and acceleration properties (dynamic sensitivity). Different combinations of first intervals and carrier frequencies were tested on each subject.

Facial nerve stimulation

The computer digital output was connected to a Grass S88 stimulator. The left facial nerve branch for the orbicularis oculi muscle was then stimulated percutaneously with small surface silver electrodes. Clusters of trains at different frequencies were tested. The kinematics effect of stimulations with or without dynamic sensitivity was compared. Finally, the behavioural effect was recorded by a webcam and offline analysed.

The closed-loop was inhibited when an EMG activity of the right temporalis and masseter muscles was recorded.

Analysis

Muscle recruitment curves were studied, and average peak acceleration was computed and compared to the kinematics data of the natural eyeblink for each patient.

Results

Natural eyeblink kinematics

Within the 10 subjects the natural blink frequency was 11-26 blinks/min (mean 17.2±5.6 blinks/min), while blink duration and its average peak acceleration were 83.5-118.2 ms (mean 110.5±11.3 ms) and 1.4-5.1 m/s² (mean 3.4±0.6 m/s²) respectively. From these data it emerges that a high variability of the natural blink parameters occurs within subjects, thus for each subject a custom fit approach is needed to reproduce the blink in the paralyzed side.

Dynamic vs static pattern

From the recruitment curves it emerged that the average peak acceleration of the lid closure is much higher when the subjects are given stimulation trains containing a dynamic pulse, than the one achieved stimulating at a carrier frequency only (Fig. 2). For example, at an intensity of 30 V the eyelid max acceleration was 1.8 m/s² when stimulated without the dynamic pulse, while it reached 3.9 m/s² (+116%) or 4.8 m/s² (+166%) with a dynamic pulse of 250 or 300 Hz, respectively. From the same experiment it is apparent that in order to obtain a full eyelid closure, the intensity of the stimulation was much lower (-15%) when using dynamic pulses. In the case illustrated in Fig. 2, the full eyelid closure was obtained at 26 V, rather than 30 V. By comparing the yellow and red/blue curves, note also that by adding a single dynamic pulse, the acceleration range dramatically widens, attaining maximum values comparable to those recorded in the natural blink.

Fig. 2 Recruitment curves showing the dynamic sensitivity of motor neurons

In the tailoring process, it is also important to underline that by keeping a constant first interval delay, the proper peak acceleration may be obtained by simply changing the carrier frequency value. Fig. 3, which depicts the changes in average peak acceleration according to different carrier frequencies, shows that the desired eyelid acceleration (in the range of 1.4-5.1 m/s²) may be obtained by setting the proper carrier frequency (75-200 Hz).

Fig. 3: Relation between stimulating carrier frequency and average max eyelid acceleration (p-Pearson: 0,95).

Discussion

In order to generate a natural-like blink, we are working at an implantable programmable device that electrically stimulates a paretic orbicularis oculi muscle, when EMG activity is detected in the healthy homologous contralateral muscle. Since there is a high variability of the natural eyeblink kinematics parameters within subjects, a custom-fit stimulation program is tailored case by case.
A complex dynamic pattern of stimulation allows the “bionic” blink to be natural-like.

A multichannel EMG recording, filtering the electrical noise of neighbour chewing muscles on the healthy side, is a main point in order to avoid the uncomfortable activation of the loop when the subjects bite.

Traditional batteries will be replaced by an electromagnetic wireless power system with use of supercapacitors.

The preparation of a multichannel A/D card containing a microcontroller to process the signal and trigger the stimulation pattern represents the next step towards miniaturization.

Conclusions
Assembling an implantable micro-device allowing the recovery of the eyeblink would be a life changing opportunity for patients affected by facial paralysis. Moreover, from this first step, a multichannel device may also be envisaged to restore both the eyeblink and smile.

References

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