

Two approaches to the optic nerve visual prosthesis.

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Abstract

Two volunteers have been implanted with an optic nerve visual prosthesis. In the first case, the spiral cuff electrode was wound around the intracranial segment of the patient's optic nerve. While the system is further improved, functional results are very encouraging. In an endeavour to develop a less invasive procedure, the electrode was placed on the intraorbital optic nerve in the second volunteer.

Contact impedance, scalp induced potentials and other device tests yielded similar results in both approaches. As expected, the phosphene perception threshold current is higher when stimulating over the duramater. On the other hand the phosphenes obtained with the intraorbital stimulation have a large size. This also contrasts with the rather small light patches generated by intracranial stimuli.

1. INTRODUCTION

Retinitis pigmentosa is a relatively frequent cause of blindness in developed countries. This progressive condition tends to evolve towards a total loss of vision while a fraction of the ganglion cells can remain functional [7,11,12]. In such cases, a prosthesis could thus be connected to the pre-chiasmatic visual pathways [15]. It is hoped that interfacing more peripheral neural structures would be easier to develop than the initial cortical approach [3].

While several groups are working on subretinal [4,5,16] and epiretinal electrodes [9,10], a first spiral cuff electrode was implanted around the optic nerve in a blind human volunteer in 1998 [14]. Work has proceeded regularly with this person [13] and a short update of the results will be presented. In this first volunteer, however, the implantation was done intracranially, immediately in front of the chiasma. This surgery uses a standard pterional transsylvian approach [8] but it involves

opening the skull and the dura mater which in itself represents a very invasive procedure.

As an alternative, a technique for intraorbital implantation [1] has been developed. Although only exposing an otherwise non-functional eye or optic nerve and, therefore more benign from a clinical point of view, this electrode placement involves a technically difficult surgical procedure. It also leaves the electrode in a less favourable position, above the dural sleeve as well as the layer of cerebro-spinal fluid that surrounds the intraorbital nerve. No such shielding exists intracranially.

2. METHODS

This study fully complies with the declaration of Helsinki. Approval by an ethics committee and a written informed consent were obtained. Candidates were recruited through patient organisations. The two implanted volunteers are totally blind in the frame of a dominant form of retinitis pigmentosa. Phosphene perception can be elicited by transpalpebral electrical stimulation in each of them [7].

The first person, a lady of 59 year old at the time of implantation, had enjoyed almost normal sight up to the age of 28 years and had lost light perception two years before surgery. She was implanted intracranially with a four contact spiral cuff electrode around her right optic nerve.

The second volunteer was a man aged 68 years at the time of implantation. His visual problems started at the age of 10 years and he had lost all light perception by the age of 35. His right optic nerve was implanted with an intraorbital cuff electrode carrying eight platinum contacts.

In both cases, each contact has an exposed circular area of 0.2 mm². Leads from the electrode are connected subcutaneously to a parietally located titanium encased stimulator itself attached to a retro-auricular antenna for the bi-directional transcutaneous transmission of signals and power. Individual stimuli consist

of a series of current pulses characterised by their intensity, duration, number and frequency as well as the contact through which they are delivered. Preliminary ‘open loop’ stimulation tests permitted to establish the threshold, localisation, size and brightness of the correspondingly generated light perceptions or phosphenes [6].

In our first volunteer, a video camera mounted on a pair of spectacles worn by the volunteer captures black and white images at 25 frames per second. They are sent to an external belt worn processor. The pictures are reduced to a 32 by 64 single bit pixel matrix. One pixel represents approximately 1° field of view. Edge detection can be applied as well.

Whenever there is a coincidence between the centre of an available phosphene and any part of the processed image, the corresponding stimulus parameters are sent to the optic nerve [2]. To avoid repeatedly inducing the same visual sensation a list of the last ten occurrences is continuously updated and the least frequently used coincident phosphene is chosen.

3. RESULTS

A few weeks after implantation, a moderately palpable stimulation box under the parietal scalp was the only clinically perceptible mark left by the surgery. A CT-scan demonstrated the adequate position of the electrodes. Surface transpalpebral stimulation proved the total preservation of the optic nerve. During the initial two or three months however, as post-surgical oedema receded, the skin thickness over the antenna dropped from 7 to 4.9 mm in our second volunteer and from 7 to below 4 mm in the lady. The transcutaneous transmission might not work properly across the initial thickening.

The electric field potentials generated by the stimulation pulses could be recorded between a point just above the nasal end of the right eyebrow and the right mastoid. Scalp voltage to stimulus current ratios of 2.4 ± 0.05 and 7.1 ± 1.7 are obtained for the intracranial and intraorbital implant respectively. The electrode impedance estimated from the potential value at the end of the constant current cathodic stimulation pulse varies with the pulse width and applied current. The following measurements were obtained for 1 mA pulses of 100 μ s duration: between 5.96 and 14.3 kOhm for the 8 different contact pairs of the intraorbital trial during surgery. Four months

later, using the stimulator titanium encasing as reference anode, the impedances varied between 2.21 and 4.65 kOhm. There was a good correlation between the two sets of values.

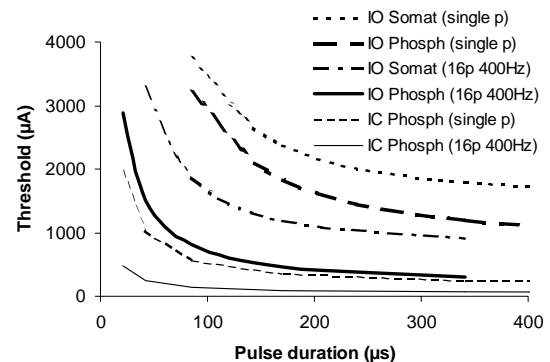


Figure 1

Phosphene perception threshold for somatosensory (intraorbital stimulation) and phosphene perceptions in the intraorbital (IO) as well as intracranial (IC) case. Standard Deviation from the traces above was 32%, 36% and 91% for somatosensory, IC phosphenes and IO phosphenes respectively.

The best fit strength-duration curves of phosphenes thresholds is plotted in Fig.1. The estimated chronaxy was 130 μ s for the intracranial implantation while a value of 190 μ s was found with the intra-orbital implant. Train stimuli and single pulses yielded the same value for this parameter. For single pulses, however, the rheobase reached 210 μ A in the intracranial case and 850 μ A for the intraorbital stimulation while; this lower asymptote fell below 52 μ A and 200 μ A respectively for trains of 16 pulses at 400 Hz.

The prosthesis induced occipitally distributed cortical evoked potentials. Phosphene perceptions described in the two cases were markedly different. While rather small patches of a few degrees and different locations were obtained with intracranial stimuli, the intraorbital alternative yielded large poorly delineated weakly coloured patches of dim brightness, centrally located or extending slightly more towards the upper hemifield. No phosphene table could be drawn in this case.

In the first volunteer, a table of 109 phosphenes in a restricted visual field of 14° vertically by 41° horizontally was build. With the help of this table, patterns could be identified (84% correct results in only 53.72 seconds per pattern after training), objects could be localised, recognised and picked up fairly accurately. The main

limitation was the scanning time required to perform the various tasks.

4. DISCUSSION AND CONCLUSIONS

The electrode impedance, the scalp potentials generated by the stimuli, the X-ray CT scan and transpalpebral phosphene thresholds proved useful tools to evaluate the status of the implant. Electrode lead continuity or possible stimulator output saturation could be detected.

As expected, the chronaxy for phosphene thresholds was not very different in the two optic nerve stimulation approaches. The slightly longer value observed in the case of intraorbital implantation was likely due to the intervening dura. The larger current threshold can easily be explained by the shielding effect of a layer of cerebrospinal fluid and the duramater but the source of the large variability is less obvious. A subdural intraorbital implantation would dramatically increase the hazard of interfering with the optic nerve vascularisation. The resulting cerebrospinal fluid leakage would also have to be dealt with.

The large size of the phosphenes obtained by intraorbital stimulation might result from a different retinotopic organisation in the orbit compared to the pre-chiasmatic stretch of the nerve. Eye movements could reduce the stability of the intraorbital electrode compared to the mechanically protected intracranial environment. However, the importance of this factor is likely to be limited by the fibrous tissue reaction that typically forms around implants and the fact that eye movements must be prevented for proper phosphene localisation.

More functional progress has been obtained with the intracranial implanted volunteer. Further improvements in the visual prosthesis can be expected from sophisticated image analysis techniques, improved stimulation algorithms and alternative training strategies. Some limitations however are linked to the reduced available visual field. This restriction is likely to result from the disease process whereby only ganglion cells subtending a limited visual field survive.

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