

Electrical Stimulation of Anterior Visual Pathways in Retinitis Pigmentosa

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PURPOSE. To explore electrically induced phosphenes in blind patients with retinitis pigmentosa (RP) in comparison with healthy subjects and to develop a screening test for candidates for an optic nerve visual prosthesis implantation.

METHODS. Phosphenes are obtained by charge balanced biphasic pulse stimulations through a surface cathode over the closed eyelids and an anode near the opposite ear. The resulting strength-duration relationship for somatosensory, phosphene, and pain threshold has been recorded in five RP patients as well as in 10 healthy volunteers.

RESULTS. In sighted subjects, the average rheobase and chronaxy for phosphene perception are 0.28 mA and 3.07 msec, respectively. For pulse durations longer than 2 msec, phosphenes are usually obtained at current strengths below the level giving rise to any other electrically generated sensation. In RP patients, however, phosphenes are not so easily obtained. One in five had no visual response at all. Another patient reported a flash perception for the longest pulse durations only. Spontaneous phosphenes interfered heavily with the stimulation in a third person. Finally, despite the higher threshold, two patients displayed normally shaped strength-duration curves.

CONCLUSIONS. The surface stimulation has proven harmless, adequate, and very helpful to ascertain that the optic nerve can be electrically activated in completely blind individuals. Long-duration stimulation pulses yield very low phosphene thresholds in healthy subjects. Anterior visual pathways activation requires higher currents in RP patients. (*Invest Ophthalmol Vis Sci.* 2001;42:291-297)

Assessment of the functional status of the optic nerve in totally blind humans is required in the frame of recent attempts to rehabilitate vision in patients with retinitis pigmentosa (RP) either with retinal implants¹⁻⁴ or optic nerve stimulation.⁵ Only late onset blindness can be considered,⁶ and candidates should still have functional retinal ganglion cells. Preservation of ganglion cells has been shown in RP.⁷ Postmortem studies have found approximately 30% surviving ganglion cells in the macular region of severely affected RP patients⁸ and a mere 20% in the extramacular regions.⁹

Before considering surgery, however, the excitability of the retinal ganglion cells should be tested in each candidate individually. The purpose of this work was to evaluate a simple and harmless method to do just that. Magnetic stimulation over the visual cortex can generate phosphenes as well as visual inhibitions.¹⁰ Different coil diameters placed around the orbit

could not elicit a visual sensation in healthy volunteers even at stimulation levels strong enough to produce unpleasant facial and trigeminal nerve activations.

On the other hand, phosphenes generated by galvanic or faradic currents passed through the orbit through various electrode arrangement have been described since the mid-18th century.¹¹ More recent attempts have used corneal electrodes under local anesthesia to obtain electrically generated visual evoked potentials in humans. For example, 5-msec anodal pulses referred to a large periorbital surface electrode yield detectable responses in the 0.3- to 2.3-mA range.¹² Optic nerve integrity testing could be done through the study of electrically evoked potentials using concentric ERG corneal electrode with 2- to 3-mA currents.¹³ For 8-msec pulses, visual perception thresholds can be as low as 0.06 to 0.09 mA in healthy subjects.⁴

Modeling the volume conductors involved indicates that the eyelid merely adds a serial skin impedance to the cornea but does not significantly modify the current flow through eye and orbit.¹⁴ An eyelid surface cathode in combination with a contralateral anode over the mastoid have been shown to activate electrically the anterior visual pathways.^{15,16}

This study concentrates on comparing the strength-duration relationship as a basic description of excitability^{17,18} in healthy subjects and RP patients.

METHODS

Subjects

Table 1 lists all volunteers with their age and gender. The Y and O labels designate the five youngest and the five oldest of the 10 healthy subjects, respectively. Most of them were students or staff members of the laboratory. All five RP patients involved, aged 45 to 73 years, were totally blind (i.e., residual light perception functionally useless even in bright daylight). These patients were recruited as candidates to have a spiral cuff electrode implanted around their optic nerve as a first step toward the development of a visual prosthesis.⁵ Diagnosis was confirmed by an independent ophthalmologic examination. Only subject D had no light perception at all, even with the strongest light stimuli (V4, thus 64-mm² object of 318 cd/m² luminance). Subject E only was found to have nystagmus and cataract, and none of the candidates had glaucoma. All ERGs were flat. Doubtful flash VEP were found in subjects B and E. No response at all was obtained in subjects C and D. Subject A withdrew from the study before VEPs were recorded.

All volunteers freely gave their consent after being fully informed. They were free to withdraw at any time. This study adhered to the Declaration of Helsinki and was approved by the Ethics Committee of the School of Medicine and University Hospital of the Université catholique de Louvain.

Instrumentation

The stimulation electrode was made of four pure silver strips of 0.1-mm thickness and 6-mm width wrapped every 90° around a rubber ring of 33-mm external diameter and a 5.2 × 5.2-mm section. The interconnected contacts thus had a total area of approximately 125 mm². They

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TABLE 1. Volunteers Involved

Name	Age	Gender	Group*
Control subjects			
1	20	F	Y
2	21	M	Y
3	21	F	Y
4	25	M	Y
5	26	M	Y
6	51	M	O
7	52	F	O
8	52	F	O
9	56	M	O
10	56	F	O
RP patients			
A	45	F	RP (10)
B	53	F	RP (36)†
C	59	F	RP (19)†
D	69	F	RP (40)
E	73	M	RP (26)

* Years of blindness in parentheses.

† History of dominant heredity.

were placed at 45° of the equatorial references so that none came to overlap the sensitive eyelid opening split (see Fig. 1).

The eyelid skin was gently rubbed with alcohol, and very little Lector II conductive gel was applied, carefully avoiding spilling over. The electrode was maintained over the eye by a Velcro ribbon strapped all around the head. The size of the electrode ring was such that only gentle pressure on the eye could result. The right eye was selected for study in all volunteers, including the healthy, to match the side of the planned prosthesis implantation.

Three interconnected 10-mm-diameter silver disc electrodes made up the stimulation reference attached to the left earlobe and the left mastoid. Initial trials suggested that a homolateral reference would induce much more unwanted activation, especially in the facial muscles.

The constant current stimulator, controlled by a Labview program, produced charge-balanced, rectangular biphasic pulses. The total stimulus duration, charge recuperation phase included, never exceeded 17 msec. The initial phase at the eyelid electrode was cathodic. Again, preliminary trials have shown the phosphene threshold to be more than 33% higher (Wilcoxon: $P < 0.001$) with the opposite polarity. Hereafter, amplitudes and durations (range, 0.2–8 msec) refer to the first phase only. A tiny sound was emitted synchronously with each stimulus.

Psychophysical Method

For each pulse duration tested, the somatosensory, phosphene, and pain threshold currents were estimated. The so-called somatosensory perception is defined here as any skin sensation, muscle movement perception, or any other nonvisual awareness of the stimulation, except for the tiny sound at stimulation time. Label phosphenes means any stimulus-synchronous visual perception.

The so-called pain must be understood here as the largest stimulus intensity used, whereas the experimenter did insist on explaining that these tests did not aim at measuring resistance to pain and that any discomfort would be considered as the highest acceptable stimulation level. Additionally, any sensation suggesting direct activation of a trigeminal nerve branch was also considered as the ceiling level, even if not painful.

Thresholds were estimated using a two-successive-staircase paradigm (limits method¹⁹). Briefly, starting with current values below threshold, the stimulus strength was increased stepwise until perceptions first occur, that is, level *a*. Next, starting well above threshold, the stimulus strength was reduced along the same steps until from current level *b* down, missing perceptions were reported. The average

between *a* and *b* was taken as the measured somatosensory or phosphene threshold. Pain thresholds were obtained only once and are thus overestimated by half the increment size. In all cases, the variance due to the incremental nature of the threshold measurement can be calculated (by integration of the error over the step-size interval) as follows: $(a - b)^2/12$.

An experimental session involved a succession of tests at different stimulation pulse durations. These were arranged in random order. Between each test, subjects were allowed to describe their perceptions in details (audiotape recorded). Each subject underwent two such sessions, which differed only by the size of the stimulus strength increments used: 38% steps in so-called rough sessions and 7% for the fine sessions.

The complete procedure was carefully explained before each session. Subjects sat comfortably in complete darkness except for the very dim indirect light produced by the partially shielded computer screen. It is expected, however, that background illumination would have little effect on the thresholds of electrically generated phosphenes.¹¹ The operator issued a warning before each stimulation.

Mathematical and Statistical Procedures

The main data collected are threshold intensity values (*It*) corresponding to a set of stimulus durations (*D*). They are related by the so-called strength-duration relationship and modeled by the classical Hill equation²⁰:

$$It(D) = \frac{Ir}{1 - e^{[-D \cdot \ln(2)]/Cb}} \quad (1)$$

where the rheobase (*Ir*) is the asymptotical value of the threshold current for pulses of infinite duration. The chronaxy (*Ch*), is the pulse duration *D* at which threshold amounts to exactly twice the rheobase.¹⁷

Rheobase and chronaxy values were computed from the data using a Levenberg-Marquadt fitting procedure minimizing the following error function:

$$SSE(Ir, Ch) = \sum_i \left(\frac{It_{exp} - It_{mod}}{It_{exp}} \right)^2$$

where *It_{exp}* represents the experimental threshold data and *It_{mod}* the threshold calculated from the Hill equation (1) for the same pulse duration.

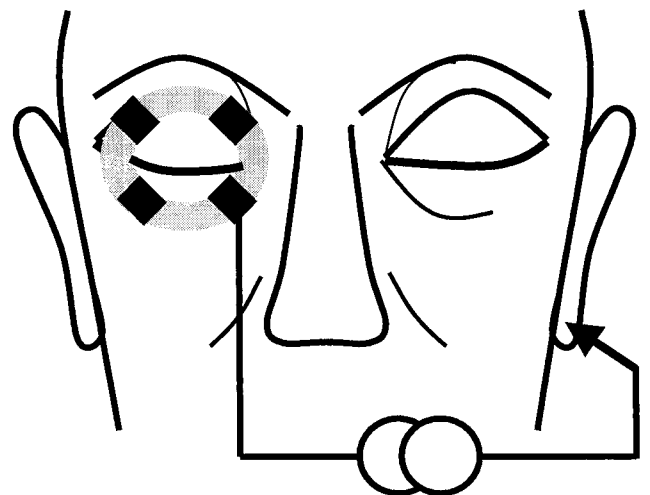


FIGURE 1. Illustration of the stimulation electrode ring (gray) maintaining the four interconnected silver contacts (black) over the right closed eyelid. The reference electrode (arrow) is on the left earlobe and mastoid.

TABLE 2. Threshold as a Function of Pulse Duration in Healthy Volunteers

Modality (msec)	Somatosensory			Phosphene			Pain		
	Avr	min	Max	Avr	min	Max	Avr	min	Max
0.2	2.15	1.20	3.12	9.99	4.70	15.05	16.65	4.50	24.95
0.3	1.74	1.18	3.09	7.21	2.99	11.09	12.62	1.80	24.20
0.5	1.51	0.91	2.92	4.37	1.81	7.00	8.53	1.87	19.25
0.7	1.09	0.88	1.97	3.15	1.36	6.48	9.01	1.73	20.45
1	1.10	0.56	1.81	1.68	0.69	2.82	5.71	1.31	12.55
2	0.97	0.52	1.57	0.85	0.47	1.28	4.98	1.31	13.29
8	0.79	0.12	2.38	0.26	0.13	0.56	3.32	0.50	9.10
Chronaxy	0.49	0.35*	ms	3.07	0.77*	ms	0.62	0.16*	ms
Rheobase	0.73	0.31*	mA	0.28	0.10*	mA	3.92	3.28*	mA
Model fit: r^2	0.83	0.43	0.99	1.00	1.00	1.00	0.96	0.78	1.00

Values are expressed as mA.

* Standard deviation.

The goodness of fit between the model and data are finally expressed as r^2 , defined as²¹

$$r^2 = 1 - \frac{\sum_i \left(\frac{I_{t_{exp}} - I_{t_{mod}}}{I_{t_{exp}}} \right)^2}{\sum_i \left(\frac{I_{t_{exp}} - \bar{I}_{t_{exp}}}{I_{t_{exp}}} \right)^2}$$

The fitting procedure was usually robust. In a few cases, phosphene thresholds yielded unstable estimations for the rheobase and chronaxy. In these, the smallest chronaxy and largest rheobase providing a good fit were used.

RESULTS

The Phosphenes

A visual sensation induced by the eyelid surface electrical stimulation was obtained in all healthy subjects and in four of the five totally blind RP patients. Around threshold, most subjects reported a dim flash. At higher stimulus intensities perception became brighter and larger. A pale smooth color was sometimes mentioned; most typical phosphenes were colorless or white, whereas occasionally a sensation of rapid movement was perceived. As a rule, the phosphenes were located close to the center of the visual field. In addition to the flashes, straight lines, lightening, arcs, circles, and often full disc shapes spanning an estimated 30° to 100° were also described, especially at higher intensities.

Patient D had occasional spontaneous phosphenes before testing. These had not been considered as a major hindrance at the time of initial recruitment. Near-threshold electrical pulses, however, induced clearly delayed phosphenes in this person. Above threshold, the stimulation did trigger a short shower of spontaneous phosphenes, similar to fireworks, as described by the patient. This spontaneous outburst eventually lasted more than one-half hour and was compared by the patient to the

phosphenes she had experienced at the very beginning of her visual loss, approximately 40 years earlier. After some rest, the spontaneous phosphenes returned to a lower level than before the test. They nevertheless further disturbed the search for the threshold of electrically generated perceptions.

Nonvisual Sensations

Tingling and pricking sensations over the right eyelid and more often the left ear were usually described as the very first sensation in both healthy control subjects and RP subjects. Sometimes, for pulse durations about 1 msec, a feeling of muscle contraction (orbicularis oculi) was reported just before the threshold for phosphenes was reached. For similar pulse durations, facial and neck muscles could be activated by the strongest stimuli.

Few occurrences of a touch sensation radiating in the forehead, the cheek, the nose, the palate, or the upper teeth were considered as signs of trigeminal activation (pain limit). Rarely stimulus-linked corneal pain has been reported during strong stimulations. More often, loosening the eyelid electrode or releasing a distorted eyelash eliminated discomfort at that level.

Data Characteristics

A paired Wilcoxon rank-sum test on the average thresholds obtained in the healthy population during the rough and fine increment sessions did not show significant differences for somatosensory, phosphene, and pain modalities ($n = 7$, $W = 47$, $P = 0.54$; $W = 52$, $P = 1$; $W = 49$, $P = 0.71$, respectively). Therefore, the results of the rough and fine sessions have been systematically pooled hereafter. A Pearson correlation coefficient of 0.982 is found between the SD and the average of phosphene thresholds in healthy control subjects. This justifies the use of ratios of the SD to the corresponding average when results from different stimulus durations are compared or combined, as in the following variability analysis.

TABLE 3. Average Thresholds in Three Age Groups

Group	Young (22.6 years)		Older (53.2 years)		RP Patients (59.8 years)	
Pulse duration (msec)	0.7	8	0.7	8	0.7	8
Somatosensory (mA)	0.98	0.57	1.18	0.98	1.24	0.60
Phosphene (mA)	2.07	0.21	3.69	0.32	8.30	3.76
Pain (mA)	5.74	2.36	10.98	4.28	23.51	7.67

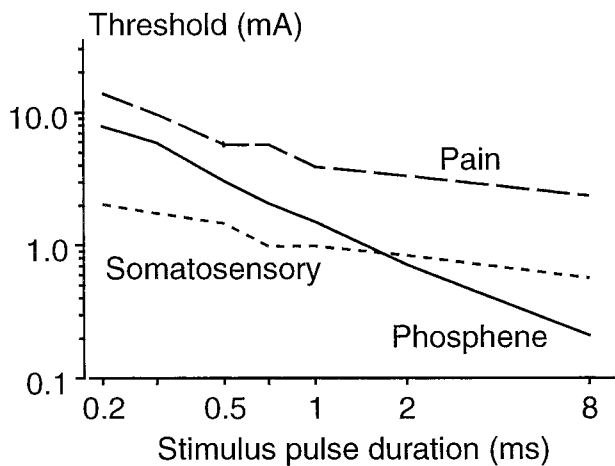


FIGURE 2. Logarithmic plot of the average somatosensory (dotted line), phosphene (full line), and pain (dashed line) threshold currents obtained in 10 healthy control subjects for different stimulus pulse durations. Note the threshold crossing just below pulse durations of 2 msec for somatosensory and phosphene thresholds.

The variance introduced by the incremental nature of the stimulation was calculated to reach 0.4% and 1.2% for fine and rough sessions, respectively. Intrasubject variability was obtained from 10 repeated tests in one control subject (subject 6), yielding variances of 12.2%, 5.7%, and 19.5% for the somatosensory, phosphene, and pain thresholds, respectively. In the 10 healthy subjects, the corresponding intersubject variability amounted to 10.8%, 24.7%, and 42.3%, respectively. Pain thresholds showed larger variations in younger than in older subjects (variances of 65.4% versus 26.3%). No such differences were observed for the somatosensory and phosphene thresholds.

Unlike chronaxy and rheobase values, the thresholds have a skewed distribution. As a consequence a logarithmic transformation was applied to estimate the 95% healthy reference range.

Except for a few outliers in the somatosensory values, a very good fit with the model Eq. (1) was usually obtained, especially for phosphene thresholds (see r^2 values in Tables 2 and 3).

The Strength–Duration Relationship

Table 2 gives the average and extreme thresholds for each pulse duration as well as the chronaxy and rheobase values with their SD for all three modalities. Student's t -test of the null hypothesis comparing the rheobase and chronaxy between somatosensory and phosphene or between pain and phosphene modalities in the 10 healthy subjects demonstrated significant ($P < 0.01$) differences. Chronaxies of pain and somatosensory thresholds were not significantly different ($P = 0.31$), whereas their rheobases were distinct ($P = 0.013$).

Phosphene rheobase and chronaxy values obtained in five healthy men (0.28 mA, 3.22 msec) and five healthy women (0.28 mA, 2.92 msec) were not significantly different (Student's t -test, $P = 0.57$ and $P = 0.95$, respectively).

The effect of age is documented in Table 3, which shows higher average thresholds in the older group than in the young group for all three modalities. Student's t -test on the null hypothesis applied to phosphene chronaxy and rheobase remained nonsignificant ($n = 5$; $P = 0.76$ and $P = 0.11$, respectively).

The relationship between the average thresholds for all three modalities in the healthy control subjects is illustrated in Figure 2. In most control subjects, for pulse durations of 2

Threshold crossing point

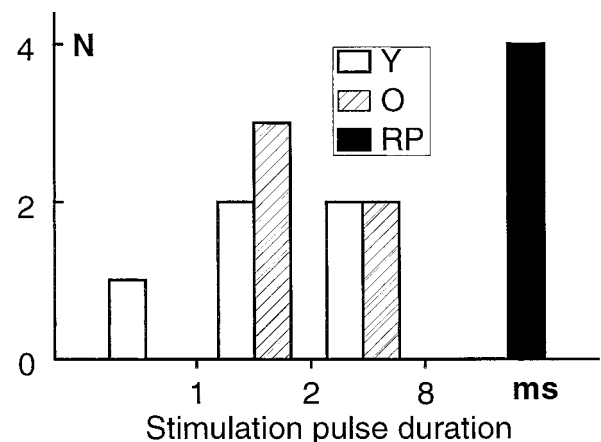


FIGURE 3. Threshold crossing point between the somatosensory and phosphene threshold lines are given in the *abscissa*. The histogram thus gives for the five younger subjects (Y, white), the five oldest healthy control subjects (O, hatched), and the four RP patients with phosphenes (RP, black), the number of individuals in whom the somatosensory crossed the phosphene thresholds below 1 msec (1 Y subject), between 1 and 2 msec (2 Y and 2 O), and between 2 and 8 msec (2 Y and 2 O). The larger than 8-msec column gathers the cases where no crossing was found.

msec or more, visual perception appeared to be the very first awareness of the stimulus before any somatosensory sensation.

The point of crossing between the phosphene and somatosensory thresholds was estimated in each subject and is presented in Figure 3 as a histogram separating data for the young, the older, and the RP groups. Note that the last column corresponds to the absence of any threshold crossing. It includes all and only RP patients (see also Fig. 4).

Threshold values obtained in the RP subjects are presented in Table 4. Figure 4 shows the average threshold behavior for all three modalities. The somatosensory thresholds are within the range of those obtained in healthy subjects (Table 2). The phosphene parameters are characterized by a larger (> 2 SD)

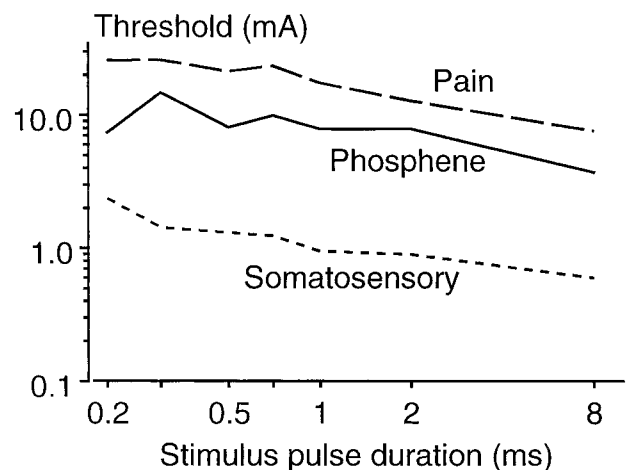


FIGURE 4. Logarithmic plot of the average somatosensory (dotted line), phosphene (full line), and pain (dashed line) threshold currents obtained in five RP patients for different stimulus pulse durations. Note that because no phosphene could be elicited in one of these subjects (subject B), the corresponding threshold trace only includes four sets of results and one of these is limited to the 8-msec point (subject E).

TABLE 4. Threshold as a Function of Pulse Duration in RP Patients A Through E

Modality (msec)	Somatosensory					Phosphene					Pain				
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
0.2			1.60	2.73					7.36					25.70	
0.3			1.20	1.65				23.40	6.06				27.70	24.20	
0.5	1.22		1.13	1.46	1.55			12.80	3.48		25.00		27.40	17.60	9.40
0.7	1.23		1.24	1.25		10.30		11.50	3.05		23.00		27.60	19.90	
1	1.18		0.70	0.96	0.98	9.04		7.41	3.23		19.80		25.00	15.50	9.25
2	0.87	0.50	0.59	1.39	1.14	6.65		5.76	7.39		15.40	10.90	15.10	16.10	6.52
8	0.65	0.30	0.32	0.97	0.76	7.88		1.97	2.75	2.45	10.10	5.30	10.80	9.10	3.14
Chronaxy (msec)	0.49		0.66	0.25	0.41	0.87		1.46	0.45		0.64		0.46	0.30	1.01
Rheobase (mA)	0.72		0.39	0.99	0.86	8.16		2.59	2.14		11.70		12.90	11.80	3.27
Model fit: r^2	0.89		0.95	0.68	0.74	0.86		0.97	0.94		0.93		0.68	0.77	0.99

rheobase and a shorter (<2 SD) chronaxy than those in healthy subjects (see Table 2). Pain thresholds are at the high limit of the normal range, but variability is too important for accurate evaluation of this parameter.

Strength-duration curves of every RP patients are illustrated in Figure 5 in comparison to corresponding average plots for the healthy subjects. No phosphene could be obtained in patient B, one of the youngest RP patients involved. RP patient E only had a visual perception at the 8-msec pulse duration, as represented by an isolated point in Figure 5. In RP patient D, who reported the spontaneous phosphenes, the strength-duration relationship was very atypical. As shown in Figure 5, her phosphene threshold remained well within the normal range (dotted lines) for short pulse durations and then suddenly outran the reference limit for pulse durations of 2 msec and longer. Phosphene thresholds in the three other RP patients remain consistently above normal.

Pain and phosphene thresholds, especially at 8-msec pulse duration, are higher in RP patients ($P < 0.05$) than in the healthy subjects (cf. Tables 2 and 4) and much more so than what could be expected from changes with age in healthy people (Table 3).

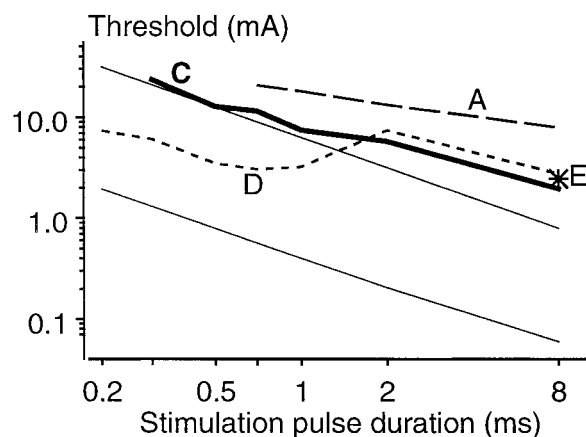


FIGURE 5. Logarithmic plot of phosphene thresholds for various stimulation pulse durations. The two parallel thin straight lines represent the 95% probability range for the healthy subjects. All other traces correspond to the results obtained in each RP patient. The top dashed line, the thick full line, and the dotted line correspond to patients A, C, and D, respectively. The only phosphene obtained in patient E at a pulse duration of 8 msec is plotted as an asterisk.

Impact of the Test on the Screening Procedure

On the basis of their absent or very poor phosphenes, RP patients B and E were rejected as candidates for an optic nerve visual prosthesis. The electrically triggered spontaneous phosphenes and the abnormal strength-duration curve were considered as incompatible with the implantation in patient D. After patient A decided to withdraw for personal reasons, patient C became the final candidate for implantation.⁵

DISCUSSION

The functionality of ganglion cells and their axons was efficiently verified in blind patients. Electrically evoked potentials^{12,13,22,23} could be advocated as an alternative technique that would not have to rely on patient's subjective perceptions. However, huge stimulation artifacts often spoil such recordings. An even more important problem is the simultaneous activation of somatosensory afferents resulting in cortical evoked potentials that could mimic genuine visual responses. On the other hand, the method presented here provides additional excitability information by exploring a broad range of stimulus pulse durations in much less time than would be required with evoked potentials.

Despite stimulating through the eyelid, the currents found to induce phosphenes are hardly larger than the smallest values required with corneal electrodes.⁴ Publications²² about electrical stimulation of the eye report that a long pulse duration is necessary to generate phosphenes. It is also accepted that for AC currents, 20 Hz is about the most efficient frequency. This is again in keeping with a chronaxy of several milliseconds.²³ A long chronaxy value (5.4 msec), comparable to the findings presented here, is also obtained when the retina is directly stimulated using intraocular electrodes.²⁴ Findings in peripheral somatosensory²⁵ and pain²⁶ nerves are similar to the somatosensory and pain excitability parameters observed here.

Brain structures require currents of approximately 100 mA to be activated by 100- μ s pulses through surface electrodes.²⁷ The comparatively extremely low thresholds observed here as well as the absence of half-field features typical for postchiasmatic stimulations²⁸ do indicate that the stimulation target is located within the orbit. In the literature, it is speculated that cells from intermediary layers of the retina are the most likely candidates.¹¹ Short-duration pulses might, however, activate ganglion cells preferentially.²⁹ This view seems to be confirmed using intraocular electrodes.²⁴ Our patient C, in whom a chronaxy of 1.46 msec was obtained with surface electrodes,

has had a cuff electrode implanted intracranially around her right optic nerve.⁵ This direct stimulation yielded a very different chronaxy of 115 μ sec.³⁰ It is thus unlikely that surface stimulation would activate the myelinated portion of the optic nerve. Further deductions from indirectly measured chronaxies are limited by the possibility that long-duration pulses could trigger repetitive action potentials.³¹ Finally, quite unlike the peripheral phosphenes obtained by eye pressure near our electrode positions,³² the electrically generated ones are located in the central field. This suggests that the complex structures of the optic nerve head should also be considered as an additional possible target.¹⁴

In healthy subjects, long stimulation pulse durations typically elicit phosphenes before somatosensory sensation can be detected. This was never found in RP patients, who have higher phosphene thresholds. Although at least some ganglion cells are considered to survive in RP,⁸ no response could be obtained in one patient (patient B). Her diagnosis has been questioned but confirmed. Another candidate (patient E) had very poor responses because phosphenes could only be obtained at 8 msec near the pain threshold. Despite the higher than normal phosphene thresholds, two candidates appeared to have normal response patterns otherwise. The higher phosphene thresholds might perhaps be linked to the reduction in the number of functional ganglion cells in RP.⁹ A much smaller reduction is known to occur with age,^{33,34} which could have resulted in the observed trend toward higher phosphene thresholds in older subjects.

The effect of electrical stimulation on spontaneously occurring phosphenes in patient D was reminiscent of the behavior of paraesthesia due to ectopic action potentials in some peripheral nerves.³⁵ In both cases, there is an immediate triggering effect of the stimulation followed by a gradual disappearance of the spontaneous activity.

The method presented has proven harmless, adequate, and useful to ascertain that the optic nerve can be electrically activated in completely blind RP patients. No adverse effect was observed. The surface stimulation avoids local anesthesia as well as any electrode contact with the cornea, and only very low levels of current are required. Although based on subjective perceptions, the strength-duration curve shape would quickly betray suspect or distorted data (see RP case with spontaneous phosphenes). Applicability of the test encompasses candidate selection for retinal and optic nerve implants as well as many situations where surgery must be decided in patients having cataract or eye trauma.^{13,36,37}

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