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Electrodes for Multifocal Electroretinography (mfERG): A Comparison of Four Electrodes Types (Elektrod untuk Elektroretinografi Multifokal (mfERG): Perbandingan Empat Jenis Elektrod)

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ABSTRACT

The purpose of this study was to compare the performance of four different electrode types in detecting the multifocal electroretinogram (mfERG) using the visual evoked response imaging system (VERIS). Multifocal ERG of 30 healthy subjects aged 17-50 years was recorded. Four different types of electrodes were used (JET contact lens, gold foil, DTL thread and c-glide carbon fiber electrodes) and the trough to peak amplitude response densities of the first order kernels (which approximated to the a and b wave of the full field electroretinogram) were compared. The JET contact lens electrode produced the highest amplitude response which was significantly different from the gold foil, DTL thread and the c-glide electrodes, but there was no significant difference between the gold foil and DTL or between DTL and the c-glide electrodes. In conclusion, contact lens electrode produced the highest response density followed by the gold foil and the DTL thread. There was no significant difference in amplitude response between the gold foil and DTL thread, therefore these two electrodes provide for viable alternatives for recording mfERG especially when there are concerns that contact lens electrode may be uncomfortable for recording periods that may take a long time.

Keywords: Carbon fiber electrode; DTL thread electrode; gold foil electrode; JET contact lens electrode; multifocal electroretinography; VERIS

ABSTRAK

Kajian ini bertujuan untuk membandingkan prestasi empat jenis elektrod dalam mengesan elektroretinogram multifokal (mfERG) dengan menggunakan sistem pengimejan visual gerak balas rangsang (VERIS). Multifokal ERG telah direkod daripada mata 30 orang subjek yang sihat dan berumur antara 17-50 tahun. Empat jenis elektrod berbeza telah digunakan (kanta sentuh JET, kerajang emas, bebenang DTL dan elektrod karbon fiber c-meluncur) dan kepadatan respons amplitud kernel urutan pertama (yang dianggarkan bersamaan gelombang a dan b elektroretinogram imbasan) dibandingkan. Elektrod kanta sentuh JET menghasilkan amplitud respons tertinggi yang berbeza secara signifikan berbanding dengan kerajang emas, bebenang DTL dan elektrod karbon fiber c-meluncur tetapi tidak ada perbezaan signifikan antara elektrod kerajang emas dan bebenang DTL atau antara bebenang DTL dan elektrod karbon fiber c-meluncur. Kesimpulannya, elektrod kanta sentuh menghasilkan respons yang tertinggi diikuti oleh kerajang emas dan bebenang DTL. Tiada perbezaan yang signifikan dalam amplitud antara kerajang emas dan bebenang DTL, maka kedua-dua elektrod ini boleh digunakan sebagai elektrod alternatif dalam pengrekodan mfERG terutama bagi mereka yang risau akan keselesaan elektrod kanta sentuh untuk pengrekodan yang mungkin mengambil masa yang lama.

Kata kunci: Elektrod bebenang DTL; elektrod JET kanta sentuh; elektrod karbon fiber; elektrod kerajang emas; elektroretinografi multifokal VERIS

INTRODUCTION

The visual evoked response imaging system (VERIS) was first described by Sutter and Tran (1992) and have been shown to be a promising tool for evaluating retinal function (Bears et al. 1995; Kondo et al. 1995; Kretschmann et al. 1995; Sutter & Bears 1995). The system consists of a computer controlled display, linked data acquisition card to record analog data detected from the surface electrode on the eye and software to perform cross-correlation between the stimulus signal and the detected input data stream. The signal used to control the display is a pseudo-random binary signal which is supplied to each of the 241 elements on the screen and a response is derived from

every corresponding element in the subject's visual field. Depending on the stimulus configuration, an electrical response map of the retina can be obtained after as little as 2.5 min of recording.

The choice of electrode is one of the important factors to be considered when recording the electroretinogram. Several types of electrodes have been developed over the years to detect the minute changes at the cornea associated with ERG. The variety of corneal electrodes used to record the ERG include saline-soaked cotton wick electrodes (Armington 1974), sclera lens electrodes which have a small silver disc embedded within the plastic lens (Riggs 1941), corneal lens electrodes with lid speculum

which have a silver button electrode sunken into the plastic around the circumference of the lens (Burian & Allen 1954), a circular platinum or gold wire electrode sandwiched between two hydrophilic lenses (Schoessler & Jones 1975), a combination of soft and hard lens electrode in which a conductive paint is painted onto the surface of the hard lens in the shape of a circular ring, after which a gold wire electrode is cemented onto the painted part of the lens (Bloom & Sokol 1977). Other types include pure aluminium vacuum deposited onto a mylar sheet (Chase et al. 1976), silver impregnated nylon threads electrode (DTL) (Dawson et al. 1979) and a gold foil adhered to a mylar sheet (Arden et al. 1979). Contact lens electrodes are recommended for single flash ERG recording for adults. Lightweight hook electrodes which come into contact with the cornea and do not interfere with the optics of the eye are commonly chosen for recording the pattern ERG (Celesia et al. 1993; Marmor et al. 1989).

Some studies have been published on the performance of different types of electrodes for recording the ERG. Gjotterberg (1986) used the flash ERG to evaluate the performance of three types of contact lens electrodes and the gold foil electrode by measuring the b-wave amplitude in eleven subjects. He found a higher amplitude response with the contact lens electrode compared to the gold foil electrode. Esakowitz et al. (1993) used the flash ERG to compare the b wave amplitude with the Burian-Allen and JET contact lens electrode, c-glide, gold foil, DTL and skin electrodes. Their results showed the Burian-Allen contact lens electrode produced the highest amplitude response, followed in order of response amplitude by the JET, c-glide, gold foil, DTL and skin electrodes. Prager et al. (1992) recorded the pattern ERG to compare the performance of gold foil and DTL thread electrodes in 32 subjects recruited from two study centres. They found that although the gold foil electrode recorded ERGs twice the amplitude of ERGs found with the DTL thread electrodes, the gold foil electrode results were twice as variable. To assess the suitability of DTL thread electrodes for ERG recordings, La Chapelle et al. (1993) compared the high frequency oscillatory potentials (OP) recorded with DTL threads and a Lovac contact lens electrode by combining results from two separate studies. Recordings were obtained from 35 subjects using the Lovac contact lens electrode and 10 subjects using the DTL threads electrode. The sum of oscillatory potential amplitudes obtained with DTL threads was half of that obtained with Lovac contact lens electrode. More recently Thimonier et al. (2008) compared the JET contact lens electrode and the gold foil in detecting multifocal ERG signals and found multifocal ERG amplitude was larger and more reproducible with the JET contact lens electrode.

The International Society for Clinical Electrophysiology of Vision recommends the use of Burian-Allen contact lens electrode for recording the ERG (Marmor et al. 2003). Although many studies have shown it produced the highest amplitude compared to other electrodes, it is also generally agreed that the Burian-Allen electrode is bulky, provides little comfort to patients and requires the

use of topical anesthesia. Furthermore it is necessary to have several sizes of the Burian-Allen electrodes to fit the variety of palpebral apertures found in clinical situations. It is well known that when a contact lens is placed on the eye with a poor cornea-contact lens relationship, corneal odema will occur after few minutes as a results of hypoxia. Because the recorded amplitude of the multifocal ERG is about 1/1000th the amplitude of conventional flash ERG and because reading need to be relatively longer, an alternative electrode which presents less disturbance to the cornea is required.

Hennessey and Vaegan (1995) measured the amplitude response of the flash ERG as a function of flash intensity using the bipolar and unipolar Burian-Allen electrodes, the unipolar and bipolar gold foil and DTL thread electrodes. Their results showed the unipolar Burian Allen and unipolar gold foil electrodes produced the highest amplitude response compared to DTL and to the bipolar Burian Allen electrodes. However they used only two subjects to compare the two types of Burian Allen electrodes and eight subjects for the comparison of other electrodes.

Many studies have shown that the contact lens electrode produced the highest amplitude, but comfort during ERG recording was equally important and the DTL has been cited to be the preferred by vast majority of patients (Beeler et al. 2007). In this study the amplitude response of the multifocal ERG recorded with the VERIS system using 4 different electrode types was measured and data from 30 subjects were recorded and compared.

METHODS

SUBJECTS

ERG recordings were taken from the right eyes of 30 healthy subjects (14 males, 16 females) with a mean age of 27 years (range 17-50 years). Advertisements were placed at various locations at the university and eye clinic to recruit subjects. The inclusion criteria were: Adults with no obvious evidence of ocular disease; corrected acuity of 6/6 or better and refractive error lower than ± 3.00 D.

RECORDING

VERIS 1 system with a 17 inch Sony colour monitor (Model CPD-1704S) was used. The subject to screen distance was 26 cm and the non-fixating eye was occluded. The subject lay supine and was required to fixate a red cross at the center of the display. The stimulus configuration used was the 103 hexagon array shown in Figure 1. Luminance modulation of each of the hexagonal element of the display was produced by the controlling computer program, which simultaneously recorded the raw ERG signal. The luminance of the elements of the display was modulated according to a pre-determined pseudo-random sequence.

The ERG signals were amplified 100,000 \times using two cascaded Grass P15 amplifiers (bandpass 3Hz to 100Hz).

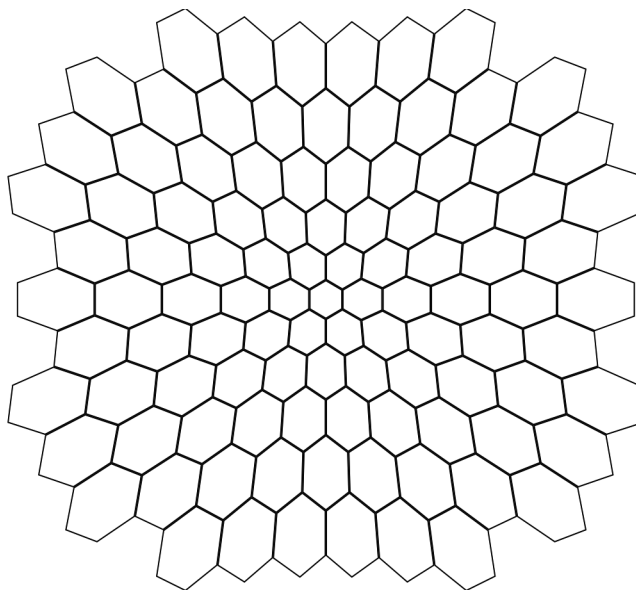


FIGURE 1. Spatial layouts of the stimulus array used in their VERIS system

The maximum luminance of the display was 100 cd/m² and the minimum was 4 cd/m².

Five recordings were taken from each subject and averaged. Each 2.5 min recording contained eight stimulus/response epochs. The trough to peak amplitude density (nV/sq deg) of the averaged waveform was measured. The amplitude density responses from the different types of electrodes were compared in the analysis.

PROCEDURE

Before the recording commenced, the procedure was explained to the subject and written consent were obtained in accordance to the University's Human Subjects Ethics Committee requirements. The right pupil of each subject was dilated with two drops of 0.5% tropicamide. The dilated pupil diameter was measured using the infra-red imaging system of a Canon Autorefractor (model RF-5). The average dilated pupil diameter was 7.2 mm (minimum 6.5 mm). Each subject was corrected for the 26 cm screen distance.

After a period of at least 30 min, the multifocal ERG of each subject was obtained using the following electrodes: the carbon fiber (c-glide) electrode, the JET disposable contact lens electrode, the DTL nylon thread silver impregnated electrode and the gold foil electrode. The testing order of electrode type was randomly chosen for each subject. The electrode impedance was measured prior to recording in each case. Except for the DTL electrode, a drop of 0.4% benoxinate hydrochloride was instilled in the right eye before an electrode was inserted. Saline was used as a wetting agent for the JET contact lens electrode before and during recording.

A gold disc ear clip electrode was placed on the left earlobe as the ground electrode and a gold disc electrode

placed on the middle of forehead served as the reference electrode. Each recording took about 14 min and the subjects were allowed to rest between recordings.

RESULTS

The mean values of the trough-to-peak amplitude density of 30 subjects obtained with four different electrodes are shown in Table 1 and Figure 2. The JET disposable contact lens electrode gave the highest amplitude density, followed by the gold foil, then the DTL and the c-glide carbon fibre electrode. A one-way analysis of variance showed there were significant differences between response densities from the 4 electrodes ($F= 12.78$, $df=3$, 116 , $p<0.001$). Post hoc tests showed that there is significant difference in amplitude density between the JET contact lens and the other three electrodes. There was also a significant difference in the amplitude density between the gold foil and the c-glide electrodes. However there was no significant difference between the gold foil and the DTL thread electrodes and no significant difference between the DTL thread and c-glide electrodes (Student Neuman-Keuls post hoc test at significance level 0.05).

Although the JET contact lens electrode produced the highest amplitude density the observed population standard deviation was also the highest. This suggests that this electrode gives the largest variability in a given population compared to the other electrodes.

How well do the results from the four electrodes agree? Figure 3 shows the bias plot obtained using the contact lens electrode as the 'standard'. Compared with contact lens electrode the other electrodes are progressively less sensitive with increasing amplitude densities. The negative slopes of the bias plot are all significantly different from 0 ($p<0.005$).

TABLE 1. The mean amplitude densities, standard deviations, standard errors found for the multifocal ERG using 4 different electrode types. The 'efficiency relative to the contact lens electrode' is derived from the slope of the linear regression relating the responses of each electrode to those from the contact lens electrode

Electrode type	Mean amplitude density (nV/sq deg)	Standard deviation	Standard error	Efficiency relative to the contact lens electrode
Carbon c-glide	29.86	10.31	1.88	0.39
Contact lens	48.72	16.76	3.06	-
DTL thread	32.79	11.16	2.04	0.52
Gold foil	37.65	11.42	2.08	0.52

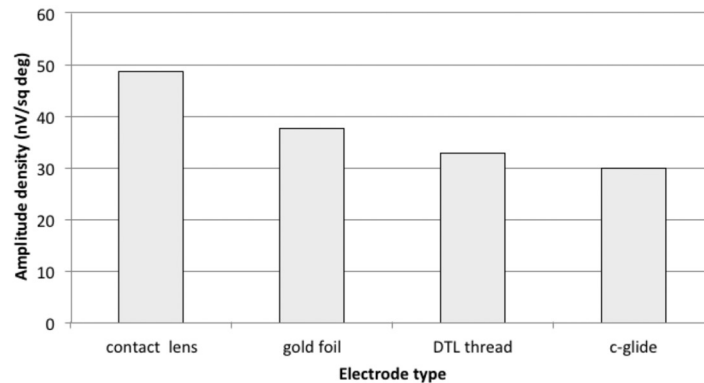


FIGURE 2. Response densities of 4 electrodes using multifocal ERG

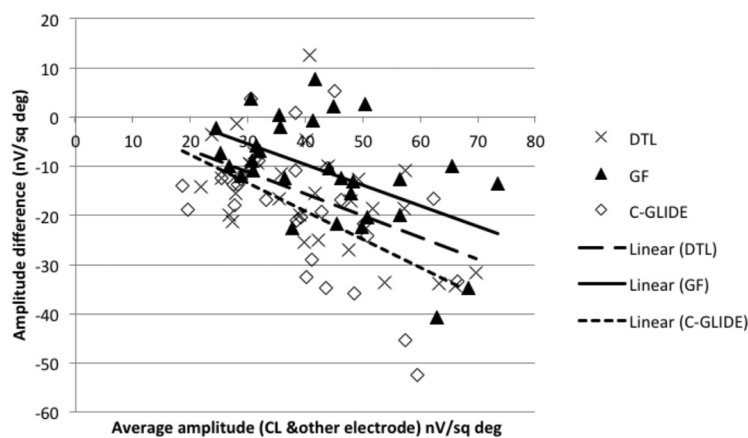


FIGURE 3. Bias plot of amplitude differences between contact lens electrode and each electrode type versus their mean amplitudes. The slope represents relative efficiency of the different electrode types compared to the 'standard' contact lens electrode

DISCUSSION

The results from 30 subjects demonstrate that the JET contact lens electrode gave a significantly higher amplitude response compared to gold foil, carbon fiber (c-glide) and silver impregnated nylon thread (DTL) electrodes for the smaller voltages found with the multifocal ERG. This result is similar to that found for conventional ERG studies (Esakowitz et al. 1993; Gjoterberg 1986; Hennessey & Vegan 1995).

It was found that the amplitude density of the gold foil electrode to be significantly higher than that found with

the c-glide electrode. This is in contrast to the findings of Esakowitz et al (1993) who reported the opposite for flash ERGs (i.e. the c-glide electrode gave a higher amplitude response than the gold foil in his study). In the present study, the c-glide electrode gave the smallest amplitude response. This difference may be due to the number of subjects used in this sample ($n=30$) compared with the study of Esakowitz et al (1993) ($n=4$) or it may be that the c-glide electrode is less efficient at the lower signal strengths found in the multifocal ERG.

The present data showed no significant difference in amplitude densities between the gold foil and DTL thread electrodes. The findings are in contrast to that of Prager et al. (1992) who reported a significantly higher amplitude response for the gold foil electrode compared to the DTL thread electrodes for 32 subjects. However they recorded the pattern ERG which is over 100× larger in amplitude than our multifocal ERG.

The best electrode is one which gives the highest amplitude density and least variability. Prager et al. (1992) provide a co-efficient of variation for their electrode comparison study using the gold foil and DTL threads. However, this coefficient of variation was derived from the population mean and the standard deviation data and thus cannot reflect the variability of electrode type under study. In another study by Mohidin et al. (1996) it was shown that the contact lens and gold foil electrodes produced the least variability for recordings taken over several occasions.

Another way of comparing electrode performance is to look at the ability of the electrode to reflect changes in a range of amplitude densities. The contact lens electrode was taken as the standard and compared the responses from other electrodes to the contact lens electrode using regression analysis. The slope of the regression lines will be zero if the other electrodes signaled the same changes in response density as the standard. The results in Table 1 shows that the DTL and gold foil electrode gave a slope of 0.52, indicating that these electrodes are half as 'responsive' compared to the contact lens electrode. The c-glide electrode fared worst. The graphs are depicted in Figure 3.

Whilst the JET contact lens electrode produced the highest amplitude density and the best relative efficiency for the multifocal ERG, it has several disadvantages in clinical use. It is only available in a single back central optic radius (7.8 mm) and therefore cannot be expected to fit all corneas well. Because the recording of multifocal ERG took about 14 min in the present study, it was necessary to instill saline to prevent discomfort and blurring when the JET contact lens electrode was used. Blinking was discouraged during the recording which exacerbated the discomfort and variable vision. In some instance, the contact lens was displaced when a subject tried to blink. Furthermore, the use of contact lens electrode required application of topical anesthetic. Others have noted similar concerns (Esakowitz et al. 1993; Gjotterberg 1986; Hennessey & Vegan 1995).

In the present study it was found that the coarse recording tip of the c-glide fiber electrode and the pre-shaped plastic hook caused temporary redness in bulbar conjunctive with which it comes in contact. While wearing the c-glide electrode our subjects seemed to be aware of ocular irritation when the effect of anesthesia has worn off. This was also not the case with the gold foil electrode, a finding also noted by Arden et al. (1979) when they introduced the gold foil electrode. However the gold foil electrode is pliable and to form an appropriate arc over the lower eyelashes required some practice and

dexterity. After repeated use, the impedance of the gold foil increased beyond 5-10 kΩ. Odom (1991) recommended that electrode impedance should be less than 5-10 kΩ in ERG recording, to minimize interference. There was also tendency for the foil to shift from its original position after repeated blinking.

The DTL appeared to be the most comfortable electrode. Many of the subjects in the present study could tolerate it without anesthesia. For long recording periods, it was necessary to check its position along the lower lid because there was tendency for it to be embedded underneath the lid after several blinks.

In a clinical situation, the electrode that provides the highest amplitude response with least within-subject variance has the greatest likelihood of separating normal from abnormal ERG responses. The JET contact lens electrode gave the largest amplitude response. However other factors such as risk to the cornea and comfort to patients need to be considered. For long recording periods and given the problems with contact lens electrode, the gold foil and the DTL threads electrodes seemed to be viable alternatives for recording the multifocal ERG.

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