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Preliminary report

Non-invasive electroretinography

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Abstract

Electroretinographic (ERG) investigations are conventionally performed by using corneal or conjunctival recording electrodes. Both types have to be placed in contact with the eye, resulting invasive and providing discomfort for the patient. This paper presents a simple technique to detect ERG potentials non-invasively. It relies on the use of a conducting liquid between the eye and an external conductor, which actually derives the ocular potential without any ocular contact. These elements are the basic components of a new type of ERG electrode, referred to as Carpi–Tomei (CT) electrode. The paper describes the assembly of prototype samples of the new electrode. Preliminary testing assessed the feasibility of the proposed non-invasive technique.

Keywords: Electroretinogram; Electroretinography; ERG; Non-invasive; Ocular; Recording electrode; Retina

1. Introduction

Electroretinography (ERG) is the fundamental ocular electrophysiologic test. It is used to detect bioelectric responses of the retina, following its stimulation with opportune light flashes [1]. It permits to perform functional evaluations of the retinal activity, by recording electric potential differences related to its response.

ERG measurements are performed by using a recording electrode in combination with a reference and a ground electrodes. These are usually located on the skin near the palpebral rima, onto the forehead or onto a ear. As a recording electrode, different types of designs are available. They can be grouped in two main categories: corneal and conjunctival electrodes. The first has to be positioned in contact with the cornea, while the second with the bulbar conjunctiva.

Corneal electrodes basically consist of a metal conductor integrated into a contact lens. Fig. 1 reports the most common types. Highly performing configurations are those which integrate a blefarostat (device to hold the lids apart), ensuring a strict corneal contact. Examples are the so-called Burian–Allen and cotton-wick electrodes (Fig. 1A,B). However, these are also the most uncomfortable. A slightly lower discomfort is offered by the Gold Lens and ERG-Jet electrodes (Fig. 1C,D). Regardless their specific implementation, corneal electrodes are capable of providing measurements with high sensitivity, low noise and high reproducibility. This is due to their corneal contact. However, for this reason this category of electrodes is highly uncomfortable, so that a surface anaesthesia is typically necessary. They can even cause corneal abrasions or edemas and need to be applied by well trained personnel. Moreover, the corneal surface must be protected with low-viscosity and anti-allergenic/anti-irritant solutions [4].

Aimed at reducing such drawbacks, conjunctival electrodes represent an alternative. They are made of metal conductors, shaped as either loops, hooks or wires, which are placed in contact with the bulbar conjunctiva, as shown in Fig. 1. Loop-like electrodes, such as the HK loop, are inserted into the conjunctival fornix (Fig. 1E). Hook-like or foil-like electrodes are usually hooked up to the lower eyelid (Fig. 1F). Wire-like linear electrodes, such as the DTL electrode, are bridge-settled over the cornea or in the conjunctival fornix (Fig. 1G). Although the tolerability of these electrodes is higher with respect to corneal devices, they still provide discomfort, as it can be argued from Fig. 1.

According to international medical directives (see for instance [5]), the surface of the eyeball is defined as a natural

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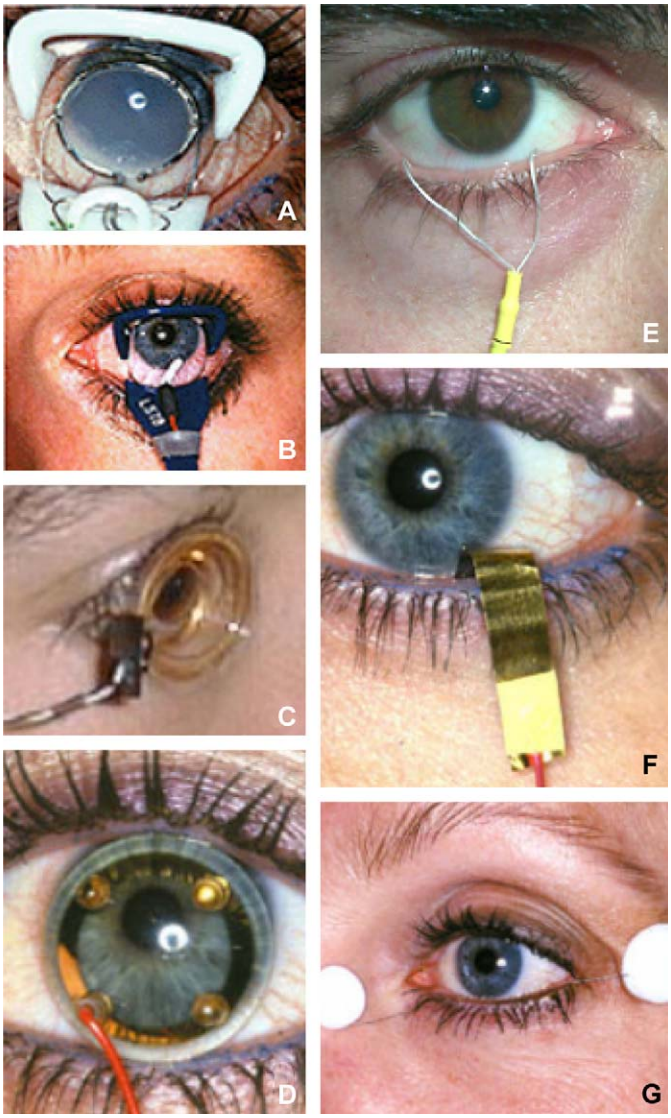

Fig. 1. Standard recording electrodes for ERG tests: (A–D) corneal electrodes; (E–G) conjunctival electrodes (pictures adapted from Refs. [2,3]).

orifice. Therefore, any device in contact with it is, by definition, invasive. As a consequence, all the conventional types of ERG electrodes, namely conjunctival and corneal, have to be considered invasive. Moreover, in addition to the considerable discomfort caused to the patient, other disadvantages affect these techniques. As an example, the application of any conventional ERG electrode requires appropriate skills of the operator and a decisive collaboration of the patient. Erroneous applications can compromise the mechanical stability of the electrode and, as a consequence, the reliability and reproducibility of measurements. These factors concur as a practical limitation of the large clinical use of electroretinography, despite its fundamental importance. Accordingly, new types of electrodes are demanded.

For this purpose, this work proposes a new recording electrode conceived to enable non-invasive detections of ERG potentials, avoiding any corneal or conjunctival contact. Following a description of the proposed concept, the paper describes the assembly of prototype samples of the new electrode and presents their preliminary testing on volunteers.

2. Non-invasive electroretinography: proposed concept

The concept here presented proposes the detection of ERG potentials by employing a non-contact electrode, enabling a technique more comfortable and simpler than the standard approaches. It relies on the use of a conducting liquid between the eye and an external conductor, which derives the ocular potential without any actual ocular contact. A scheme of this concept, compared with a conventional corneal technique, is reported in Fig. 2.

In order to obtain a system capable of implementing this simple concept, the following components can be foreseen:

- a pair of plastic glasses, with optically transparent lenses, a flexible anatomic structure and watertight gaskets, capable of containing a liquid to be interposed between the eye and the glasses themselves;
- an electrically conducting and optically transparent liquid, such as a saline solution, to be inserted and contained within the volume delimited by both the eye, the internal surface of the glasses and the peri-orbital skin portions covered by them;
- a recording conductor to be dipped into the conducting liquid between the eye and the glasses, avoiding any contact with any ocular portion or peri-palpebral region.

According to the conventional nomenclature of ERG electrodes, this system, recently patented [7], is here referred to as Carpi–Tomei (CT) electrode. Fig. 3 shows drawings of a possible implementation.

Following the arrangement of the conductor into the glasses, these are applied to the patient and are filled with the conducting liquid. As a consequence, the recording conductor results dipped into the liquid and can be used to derive non-invasively the ocular potential, by exploiting the conductivity of the interposed liquid medium. The ERG signal is recorded by using the CT electrode in combination with standard reference and ground electrodes.

3. Materials and methods

In order to assemble prototype samples of CT electrodes, standard disposable DTL electrodes were selected as actual recording conductors and were fitted into glasses for swimmers. Each DTL conductor was linearly arranged into the glasses and fixed to them in proximity of each lens with adhesive supports. A water-based sterilised solution rich of potassium (based on a proprietary formulation suitable for ophthalmologic uses) was used as a transparent conducting liquid. The liquid had a resistance of approximately 80 kΩ/cm.

Fig. 4 presents a prototype version of a CT electrode. This type of prototypes was preliminarily tested, by performing ERG measurements on volunteers. In order to apply standard

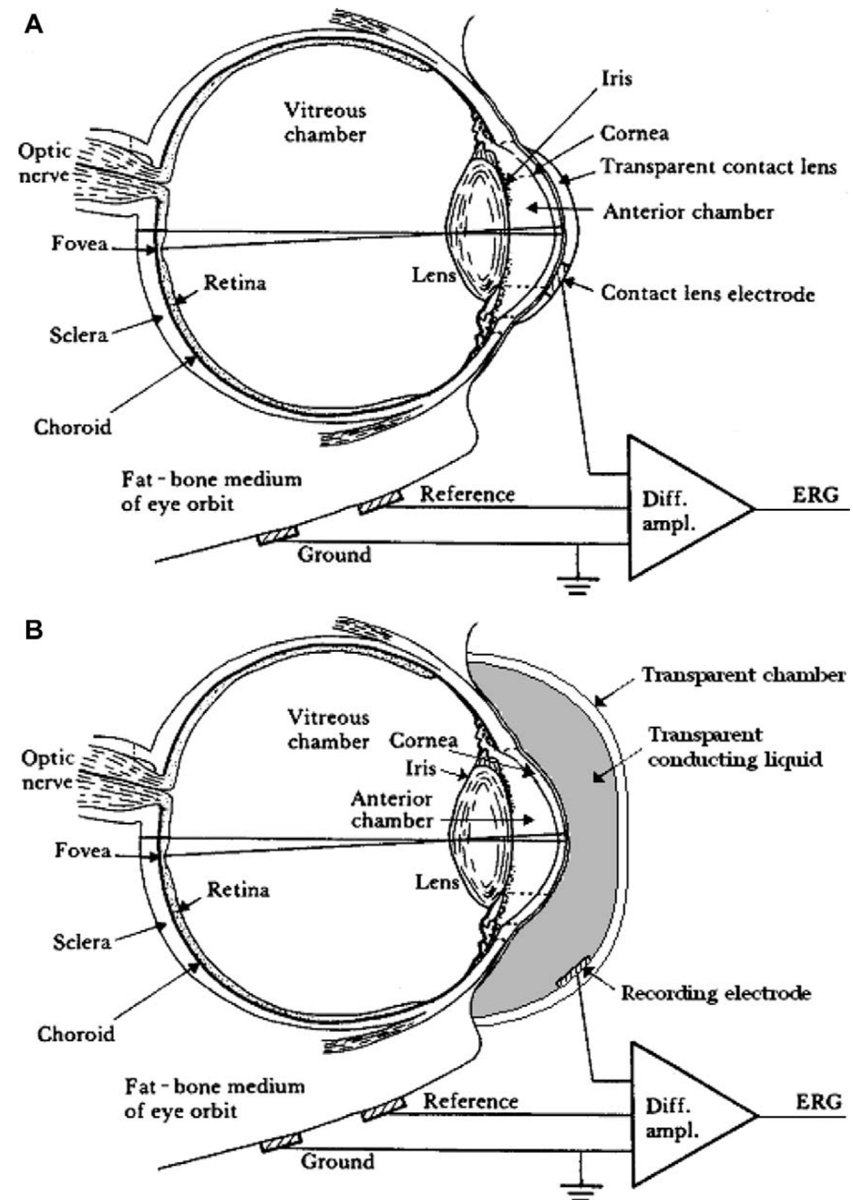

Fig. 2. Principles of measurement of an ERG response: (A) standard invasive technique with a corneal electrode (figure adapted from Ref. [6]); (B) proposed non-invasive technique.

light stimuli (by means of a classical Ganzfeld cupola) and to record massive ERG responses, a commercial instrumentation (model MonEl2, Metrovision, France) was employed. The following section describes the performed tests and reports their results.

4. Results

The recording performance of a CT electrode was evaluated in comparison with a standard corneal electrode on a 56-years-old voluntary woman. For this purpose, a Henkes electrode was selected and the volunteer was subjected to independent ERG tests with the two electrodes. Fig. 5 shows, for each electrode, a couple of signals consecutively recorded from the same eye. As a result, the CT electrode permitted to record peak-to-peak amplitudes of 214.0 and 210.7 μV, while the corneal electrode provided 420.5 and 434.4 μV.

In order to compare the CT electrode with a conjunctival electrode, a second series of tests was performed on a 36-years-old voluntary male. An HK loop was selected as a standard conjunctival electrode. Signals consecutively recorded from the two different electrodes and for both of the eyes are reported in Fig. 6. As a result of these tests, the CT electrode provided peak-to-peak amplitudes of 287.6 and 291.0 μV for the right and left eye, while 270.0 and 277.0 μV were obtained with the conjunctival electrode, respectively.

5. Discussion

The choice of an appropriate recording electrode is of fundamental importance for ERG tests, likewise any other electro-

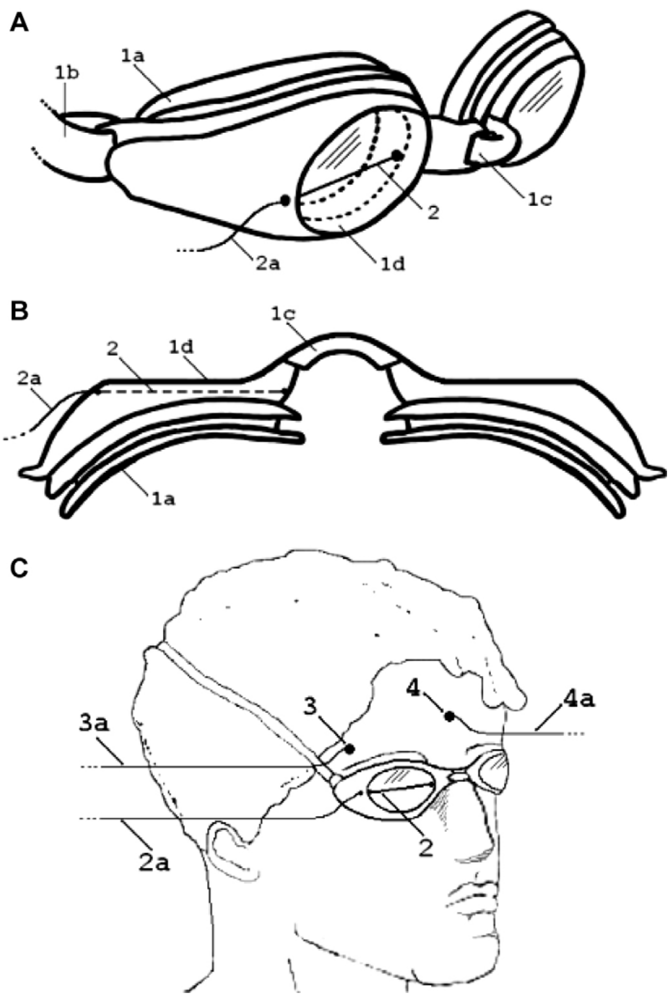

Fig. 3. Schematic drawings of a CT electrode: (A, B) structure of the electrode, consisting of a pair of plastic glasses embedding gaskets 1a, head band 1b, nasal bridge 1c, transparent lenses 1d and a recording conductor 2, connected to the measurement instrumentation with a lead 2a; (C) use of the electrode, in combination with cutaneous-type reference 3 and ground 4 electrodes having connection leads 2a, 3a, 4a.

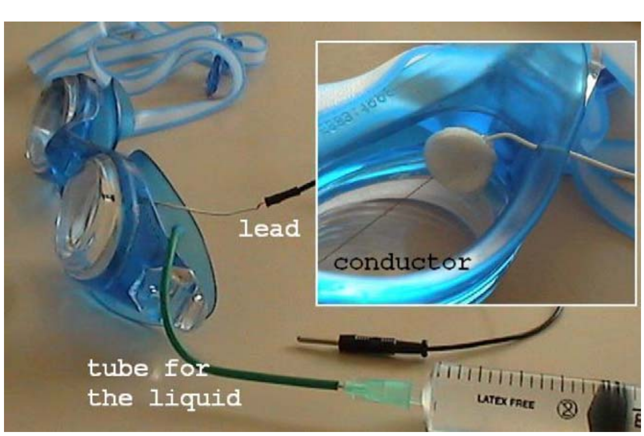

Fig. 4. Prototype CT electrode. The glasses are equipped with a thin linear recording conductor (visible in the inserted image), its lead and a small tube for the insertion of the liquid.

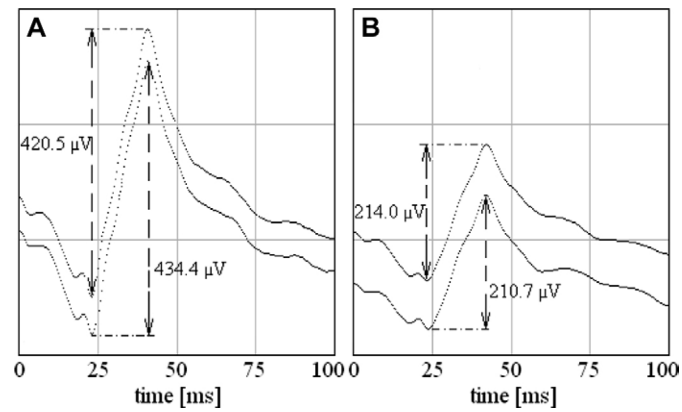

Fig. 5. A couple of massive ERG responses recorded from the same eye of a volunteer: (A) Henkes corneal electrode; (B) CT electrode.

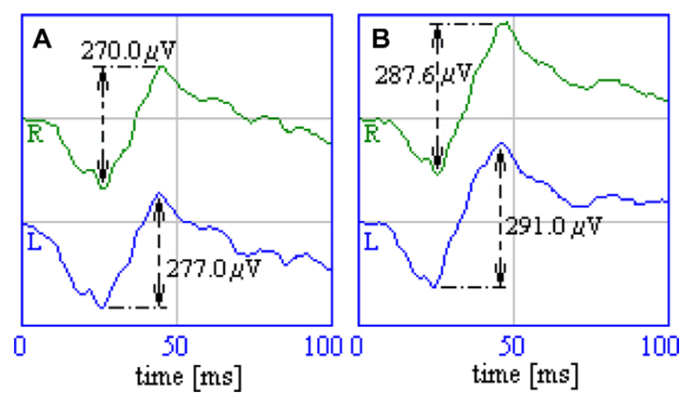

Fig. 6. Massive ERG responses simultaneously recorded from the right R and left L eye of a second volunteer: (A) HK loop conjunctival electrode; (B) CT electrode.

physiological measurement. According to their different site of application, corneal-type electrodes enable recordings with a higher response in comparison with conjunctival electrodes [8]. However, the superior performance of corneal electrodes implies higher invasivity, as previously shown.

As an alternative technology, non-invasive CT electrodes, performing contact-less ERG detections by means of an interface solution, seem to offer interesting properties. The preliminary investigations here reported suggest the feasibility of the proposed technique and its ability of detecting useful responses. According to these preliminary data, CT electrodes show response amplitudes slightly higher in comparison with conjunctival electrodes, while halved with respect to corneal electrodes. However, their ability of accurately providing the typical shape of an ERG signal (regardless of its amplitude) can be considered the main advantageous property for the potential usability of this non-invasive technique.

Nevertheless, future extensive investigations on a large set of volunteers are necessary in order to assess the actual performances of CT electrodes with a statistical significance. Such validations are currently in progress and will be presented in future communications.

In addition to the non-invasivity, CT electrodes offer several advantages or opportunities when compared to standard technologies. They include:

- a full respect of all the ocular and peri-orbital structures;
- absence of anaesthesia;
- absence of blepharostats;
- absence of wires close to the eye;
- high mechanical stability of the recording conductor;
- ease of use;
- particular indication for subjects presenting the 'dry eye' pathology and individuals able to endanger the mechanical stability of a traditional electrode;
- possible selections of different positions of the recording conductor;
- possible use of different types of actual recording conductors.

These features encourage further investigations of CT electrodes as a possible alternative to conventional techniques for ERG recordings.

6. Conclusion

A new ERG technique enabling completely non-invasive measurements of ocular electric potentials has been presented. The technique employs a conducting liquid as an electrical interface between the eye and an external conductor, which derives the ocular potential avoiding any contact.

Prototype samples of the new CT electrode were assembled and preliminarily tested. The feasibility of the proposed non-invasive technique and its efficacy in providing useful ERG responses was assessed.

In order to demonstrate the actual clinical validity and efficacy of CT electrodes, deeper and systematic investigations are currently in progress.

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