Principles and Practice of Clinical Electrophysiology of Vision

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PART V

Equipment for Visual Electrophysiological Testing

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Electrodes for Clinical Electrophysiological Testing

Stuart G. Coupland

ELECTRORETINOGRAPHIC ELECTRODES

Many designs of electroretinographic (ERG) electrodes are presently available, including contact lens, gold foil, microfiber (DTL), as well as skin electrodes. Clinical ERG is obtained with the electrode placed at some distance from the structure producing the signals of interest. The ERG signals are conducted from their retinal generator sites through various tissues to the electrode. Each electrode type has its own characteristic impedance, recording characteristics, and inherent artifacts. Qualified electroretinographers should be aware of electrode characteristics and carefully choose the electrode type that is most practical for their recording situation. Typically, an ionic bridge is used to establish an electrically conductive medium between the metallic electrode and the surface of the eye or skin. Electrodes are usually composed of silver, gold, or platinum metals for their conductance properties and because of their stability.

Artifacts during ERG recording often can be traced to the electrode system. Typically, these electrode-related recording artifacts fall into one of three categories: those related to electrode polarization, factors relating to electrode slippage or movement, and the photovoltaic artifact. Care must be taken that both the active ERG electrode and its reference electrode be of the same metallic type. When two electrodes are made from the same metal, the potential difference between them is usually around zero, but slight impurities in the metal and possible surface contamination can cause differences in electrical potential. It can be demonstrated that significant potential differences between metals can be very large compared with the magnitude of the ERG activity measured at the cornea or surface of the skin.

Fortunately, when ac-coupled amplifiers are used, these steady potentials are blocked by the coupling capacitors in the input circuit, thus reducing the effect of electrode potentials. If DC-coupled amplification is used, then electrode potential artifacts can be significant: they may cause amplifier blocking and can give rise to baseline drift that may be reduced only by using more stable electrodes. Electrode potentials can be minimized by careful preparation, by ensuring that all electrodes are of the same metal, and by avoiding contamination of the electrode surfaces.

Eye movement and electrode movement are two sources of potential artifact that can greatly affect the quality of ERG recordings. Movement or uneven fitting of contact lens electrodes on the cornea can produce artifacts in the ERG recording. Unfortunately, ERGs recorded from any electrode can be contaminated by eye movement artifact. Techniques for the digital subtraction of eye movement artifact from flash ERGs[14] as well as pattern ERGs[23] have been described and found useful for obtaining pure ERG tracings.

An additional source of artifact occurs when photic stimulation strikes the electrode surface and generates a photovoltaic signal that appears as a spike early in the ERG recordings. Fortunately, photovoltaic artifact can be dealt with quite easily by shielding the electrode surface from the light source.

Contact Lens Electrodes

The first description of the use of contact lens electrodes for ERG recording were described by Riggs, who developed a clear, nonirritating lens that could be fitted to the subject's eye for prolonged ERG recording sessions.[34] Several variants of contact lens electrodes have been developed over the years.[8, 23, 24, 38, 39, 41] Contact lens electrodes are the recommended standard for clinical recordings because of their ability to give reliable and reproducible recordings.[31a]

The most frequently used contact lens electrodes are the Burian-Allen and Henkes[1] assemblies.[8, 19] The Burian-Allen assembly makes use of a large speculum that holds the eyelids apart and contacts the scleral surface. A smaller clear corneal contact lens is held against the cornea with a spring assembly. The force exerted on the cornea by the spring mechanism of the Burian-Allen speculum contact lens has been measured at 10 g.[44]

A circular silver wire around the circumference of the contact lens makes the actual contact with the cornea and provides an active electrode. A reference electrode is provided within the surface of the scleral speculum for bipolar ERG recordings. For monopolar ERG recording, a forehead or indifferent ear electrode reference is used.

Although uncomfortable, the Burian-Allen electrode assembly can be used for a period of several hours, although a session of no more than 30 minutes is recommended. Disadvantages of this lens include rare corneal abrasion, conjunctival abrasion, and irritation produced by movement of the lens assembly. Although frank abrasions are rare, they occur, and minor trauma can be seen in some cases if the patient's cornea is stained by fluorescein. In cooperative patients, corneal staining is often directly proportional to the skill of the tester in inserting and removing the lenses. A 1% methylcellulose solution drop on the contact lens prior to insertion helps protect the cornea.

Glass contact lens electrodes employing a dome or cup containing isotonic saline and methylcellulose have been described.[19, 21, 38, 39, 41] In 1951 Henkes described an electrode that enjoys popularity today among clinical electroretinographers.[19] This corneal contact lens electrode maintains electrical contact with the surface of the cornea through a dome or cup filled with isotonic saline and methylcellulose. A low vacuum was maintained by suction, and this ensured a good contact with the surface of the eye.

While the Burian-Allen and Henkes' corneal contact lens electrodes have similar impedance and recording characteristics, a significant difference in the degree of susceptibility to corneal injury has been demonstrated in diabetic patients. Vey et al. investigated a series of 57 diabetic patients who underwent standard ERG recordings with subsequent slit-lamp examination utilizing fluorescein strips and cobalt blue light.[44] Twenty-eight patients were examined with the Burian-Allen speculum-type corneal electrode, while 29 patients had ERG recordings performed by using the Henkes' bipolar low-vacuum corneal electrode. Subsequent biomicroscopy with fluorescein demonstrated that over 30% of those patients examined by using the Burian-Allen electrode demonstrated disruption of corneal epithelium whereas corneal changes were only observed in 7% of those patients tested with the Henkes' electrode assembly. The authors concluded that due to the abnormal susceptibility to corneal injury displayed by diabetics, the Henkes' low-vacuum electrode was their recommendation for standard ERG testing in these patients.

However, it should be noted that many investigators have not found significant corneal changes from the use of Burian-Allen lenses when placed carefully and not left in for excessive amounts of time.

The use of a soft contact lens under a hard lens to cushion and disperse the direct pressure on the cornea has been advocated, and comparable recording characteristics have been demonstrated.[6, 17] Schoessler and Jones have described a soft hydrophilic contact lens electrode with excellent recording characteristics.[37] This electrode is formed by a fine gold or platinum wire sandwiched between two soft contact lenses. These investigators claim that their recording electrode is more comfortable and stable than hard contact lens electrodes and provides minimum obstruction to vision. A comparison of the recording characteristics of the standard Burian-Allen speculum-type electrode assembly and a soft contact lens electrode revealed that while the amplitude of the b-wave recorded with the soft contact lens assembly is comparable to that when using the Burian-Allen type electrode the signals were less stable over recording sessions lasting several hours.[11] This lack of recording stability was evidenced by increased high-frequency noise superimposed over the ERG waveform. Rehydration of the soft contact lens system with 0.9% saline only temporarily reduced the high-frequency noise artifact. While the soft lenses were more comfortable to wear, they required frequent rehydration since the outer soft lens was not in contact with the moistened conjunctiva and would rapidly dehydrate. As the outer lens desiccates, it begins to deform and allow air to enter the interlenticular space, thereby producing an increasingly noisy ERG recording.[11] Unlike Schoessler and Jones, the experimenter found that the soft lens electrode assembly was less stable and did not remain centered on the cornea. In addition, the hydrogel lens sandwich was too delicate to be useful in clinical recording situations. Other attempts at hydrogel lens construction have recently been more successful.[5]

Recently, plastic disposable ERG electrodes have been advocated. These plastic ERG contact lens electrodes are light and relatively inexpensive and are disposable following testing. The recording characteristics compare favorably with the Burian-Allen system.[18] Like all corneal lenses, topical anesthesia is required. While all corneal electrodes generally give excellent-quality ERG waveforms in cooperative adults with a few exceptions,[31] they may be poorly tolerated by children, who may require restraint or sedation. Often gentle persuasion, sending the parents from the examination area, and if the child is misbehaving, testing only one eye works well in children; sedation can thus be avoided.

Gold Foil Lid-hook Electrodes

While the corneal contact lens electrodes is the accepted standard for performing ERGs, there are circumstances when it is preferred to use alternative electrodes because they are more comfortable or when the patient refuses to try contact lens electrodes. An electrode that employed a polyethylene film (Mylar) strip coated on one side with aluminum and bent into a J shape was first reported to produce high-quality ERG recordings without the use of typical anesthetic.[9] Unfortunately, the aluminum coating was less than ideal because it tended to unbond from the Mylar surface at low levels of alternating current.[4, 7] A gold-coated Mylar (GCM) electrode was first described in which the gold surface did not unplate and in which excellent ERGs were obtained.[7] The curved tail of the J shape rode on the cornea and produced some changes in the corneal epithelium of 35% of the patients tested.

A low-mass, inexpensive electrode described by Arden and associates[4] was constructed from gold foil applied to Mylar and provided ERGs that were very similar to those obtained by more conventional contact lens electrodes. The gold foil electrode is very flexible and, when inserted into the lower fornix and bent to lie on the cheek barely, touches the corneal margin. A junction wire was connected to the gold foil electrode and led to an insulated standard electrode wire that was also taped against the cheek. The uninsulated junction wire was not allowed to touch the skin. While initial corneal anesthetic was recommended in the past, current practice is to use no anesthetic. In any case, once the anesthetic wears off, no additional topical anesthetic is required. Arden reports that the gold foil lid-hook electrode produced slightly smaller responses than the Karpe lens did and had some higher-frequency components superimposed on the ERG waveform. One problem is that they may shift or fall out during testing and, if uncomfortable to the patient, tearing may effectively short the electrode and give no signal. The gold foil electrode tends to be better tolerated by patients than standard contact lens electrode assemblies are, and this makes it possible to use the gold foil electrode on young children with congenitally malformed or narrow palpebral fissures as well as patients immediately following cataract or corneal surgery.

The fact that the gold foil lid-hook electrode does not interfere with the optics of the eye makes it ideal for pattern ERG recording. Recently, Gjötterberg compared several contact lens electrodes with the gold foil lid-hook assembly in 11 healthy eyes recorded on two occasions.[18] It was reported that 9 of 11 patients preferred the gold foil electrode to the Burian-Allen or low-vacuum contact lens electrodes, although these latter electrodes produced larger-amplitude responses with smaller intertest amplitude variability and thus are better for research protocols. Disadvantages of the gold foil are the foil may fall out in elderly patients with lax lids. It can easily be blinked out, and the junction is fragile, so after several usages the electrode becomes noisy. If it is placed >15 mm from the medial fornix, the voltage recorded declines.

Honda et al. recently developed a disposable electrode for ERG recording that was made from anomalous polyvinylalcohol (PVA) gel.[20] This new PVA hydrogel electrode was made of low-cost material that could be discarded after use. The electrode was cut in the shape of a lid hook and could be inserted in the lower fornix like the gold foil lid-hook electrode. The PVA electrode was considered to be very stable without electrical polarization because it contains no metal. It was claimed that patients felt no discomfort during recordings and that the electrodes produced no corneal injury.

DTL Fiber Electrode

Dawson, Trick, and Litzkow (DTL) described a very low mass, silver-impregnated microfiber corneal electrode for clinical ERG.[15] This electrode was based upon an extremely low mass conductive thread that makes contact with the tear film of the eye and is electrically coupled to an insulated wire. The individual fibers of the nylon thread are approximately 50 μm in diameter and are impregnated with metallic silver. The thread is usually draped in the lower fornix, although alternate methods using a holder to position the electrode across the eye have been described.[43] Simultaneous ERGs recorded from DTL fiber and Burian-Allen electrodes have been compared, and generally the DTL b-wave amplitudes are somewhat lower than the corresponding responses recorded with corneal lenses.[15, 16]

The advantages of the DTL system lie in the area of subject comfort, optical quality, and reduced electrode impedance.[16] The DTL system is well tolerated by children and by adults with keratitis. Like the gold foil lid-hook electrode, the DTL does not obscure the optics of the eye and therefore is superior for recording the pattern ERG. It is not "blinked" out of the eye like the gold foil electrode, but this may not be an advantage since if the fiber is displaced toward the lower fornix the signal size is reduced.

Skin Electrodes

The possibility of recording ERGs in response to flash and pattern stimulation without placing electrodes in the eye has specific advantages, especially in the testing of children and infants. However, skin electrodes should not be used unless there is no other method of obtaining the test from a patient. ERGs recorded through the periorbital skin surface have been described.[1, 12, 22, 25, 36, 40, 42] Tepas and Armington used skin electrodes placed on the nasal and temporal canthi and reported that averaged ERGs could be reliably recorded to a wide range of stimulus conditions.[42] Larger-amplitude ERGs have been reported with subsequent head rotation to displace the cornea toward the active electrode.[40] The ERG signals produced are smaller in amplitude, noisier, less reliable, and more variable than corneal ERG recording. Standardized placement of the skin electrodes is important to an individual laboratory's ability to give reliable interpretation when using this technique. The dermal electrodes are better tolerated, and the recording quality may be acceptable for many clinical recording situations in infants and young children, particularly if the patient will not allow testing with a corneal contact lens.

While dermal electrodes have been used for ERG recording for some time, there are few reports that directly compare their performance against standard contact lens assemblies. Recent investigation comparing the performance of dermal electrodes against the popular DTL fiber and the new PVA hydrogel electrode in 32 eyes has been reported.[12] ERGs were simultaneously recorded with dermal electrodes along with either DTL or PVA gel electrodes under four standardized flash conditions.

The use of simultaneous dermal recordings ensured that any differences observed were not due to adaptational, endogenous, or environmental factors. Under all four stimulus conditions the skin ERGs had consistently shorter a- and b-wave implicit times. Generally, the skin ERGs were about half as large in amplitude as the averaged DTL or PVA ERG recordings. Because of the advantages of signal-averaging techniques in increasing the signal-to-noise ratio, skin electrodes have been used in detecting retinal oscillatory potentials[36] as well as in recording the pattern ERG.[1, 22, 25] The problem of increased variability with skin electrodes has led the ERG standardization group to recommend that they should be used only in exceptional circumstances.

Electrodes for Direct Corneal Recording

To faithfully record the slow ocular potentials such as the c-wave and the h-wave (the "off c-wave") of the ERG, a DC recording system must be used. Unlike the recording of the flash and pattern ERG where commercial equipment is available, most laboratories recording the slow ocular potentials have designed apparatus specifically for this purpose. Recently, Nilsson and Andersson have described a method for DC recordings of slow ocular potentials.[32] Their equipment can also be used for recording the light peak and dark trough of the electro-oculogram (EOG). These investigators describe the use of a polymethylmethacrylate (PMMA) contact lens electrode filled with a combination of methylcellulose and saline. A similar PMMA-saline–filled chamber is attached to the forehead, and the lenses are connected by means of a saline-agar bridge to matched calomel half-cells. Electrode movement was reduced by applying suction on the contact lens. Their method has been used previously for studying the c-wave in both humans[28, 33] and in animals.[29, 30] While there are advantages to using the DC technique for recording, there are numerous technical problems related to both the electrodes and the stability of the recording system in humans.[28, 33, 35]

ELECTRO-OCULOGRAM ELECTRODES

The EOG was first introduced in its clinical form by Arden and collegues to indirectly measure the standing potential of the eye.[2, 3, 26, 27] This group pioneered the use of EOG to document retinal pigment epithelium function in normal and clinical populations. The electrodes used were nonpolarizable silver chloride balls sunk in plastic flanges pressed against the skin and held in place with adhesive tape. The authors claimed that bared silver wire secured by collodion gauze was equally effective but that normal electroencephalographic (EEG) electrodes were not recommended: because of their large size they could not be placed close to the canthi.[3] Since that time subminiature Ag-AgCl skin electrodes have been developed and are most commonly used in EOG. The Arden method of using skin electrodes and ac recordings has become the conventional technique for recording the EOG. The standing potential of the human eye can be studied by means of direct recordings using a combination of suction contact lens, calomel electrodes, and DC amplification,[32] and this procedure is described in more detail in the previous section on DC recording techniques.

Visual Evoked Response Electrodes

The visual evoked response (VER) is usually recorded with scalp electrodes composed of gold or silver. The best recording electrode is chlorided silver, and the worst is stainless steel.[10] Although reversible Ag-AgCl electrodes are probably better than nonreversible electrodes for ac recording, they are not essential unless the electrode surface area is small. Care must be taken to ensure that all electrodes are made of the same metal because potential differences between different metals can be very large when compared with the magnitude of the electrical activity of the brain.[10] Most laboratories recording clinical VERs use either gold, silver disk electrodes, or chlorided silver electrodes held against the scalp with collodion-impregnated gauze or paste.*[10] Isotonic electrode jelly is used to maintain the bridge between the electrode surface and the scalp. Clinical visual electrophysiologists and technicians must be aware that the electrodes are a vulnerable but vital part of the recording system and should be treated with care.

**A recently introduced form of conductive bentonite (Nippan Kogen Kogyo) is as good an adhesive as collodion!*

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