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A Silver-Silver Chloride Electrode for
Electrodermal Measurement

by

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1. This work was done during the tenure of a USPHS predoctoral fellowship in the laboratory of David T. Lykken.

Abstract

An electrolytic method is presented for the preparation of a silver-disc type Ag-AgCl electrode which has low bias potential and drift, moderate resistance and low polarization, is relatively durable, and can be easily replated if damaged or contaminated. The electrode can be used for measuring either skin potential or conductance and is compatible with a previously published device which compensates for non-isothermal electrodes in skin potential recording. A convenient electrode paste is described which does not dry out quickly and can be stored indefinitely. Although these electrodes have been used only in electrodermal measurement, the design might be useful for the recording of other peripherally assessed bioelectric activity as well.

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Some of the properties desired in a skin potential (SP) electrode are low bias potential, high stability, ease of construction and maintenance, and convenient physical characteristics (e.g., size, durability, etc.). Skin conductance (SC) measurement also requires relatively low and stable electrode resistance and polarization. In both cases the electrolytic conducting medium, or electrode paste, must be compatible with both the electrode surface and the skin. While no system meets these criteria completely, it is generally agreed that silver-silver chloride (Ag-AgCl) electrodes provide the closest approximation. Many approaches to Ag-AgCl electrode construction have been described (Lykken, 1965; Ives and Janz, 1961; O'Connell, Tursky, and Orme, 1960). The silver-disc type, while less expensive and easier to construct, has generally been considered inferior to other more complex and expensive designs. Venables and Sayer (1963), however, developed a simple disc electrode which is functionally competitive with the more complicated arrangements.

A primary disadvantage of Ag-AgCl electrodes, in general, is their vulnerability to contamination and physical damage. Any such insult usually renders the electrode permanently unusable. Although Venables and Sayer do not discuss the sturdiness of their electrode, similar preparations made in this laboratory were considerably more durable than, for example, the sponge type described by O'Connell and Tursky (1960). Damage to the Venables-Sayer electrode, however, is generally irreparable.

While the AgCl layer can be removed with dilute ammonia, the bare silver re-etched and the electrode replated, this process is tedious and does not result in as high a quality surface as the original. The procedure described below produces an equally efficient Ag-AgCl disc electrode which is easily replated and consequently has longer life.

Description

Discs $1/4$ inch in diameter and $3/16$ inch in width are cut from a rod of high purity silver (99.999%) and machined smooth. A fine plastic-coated tinned copper wire is soldered to one end of the disc (Fig. 1,a), allowing no solder to run to the edge, and the unit washed in acetone. Plastic (acrylic) cups $5/16$ inch in length and $3/8$ inch in diameter are turned out to an I.D. a few thousandths under $1/4$ inch (Fig. 1,b). After a $1/16$ inch hole has been drilled through one wall near the base, the cups are washed with detergent and hot water, and dried. The silver disc unit is dipped in low viscosity epoxy cement and pressed into the cup so that the lead wire extends from the small hole at the base, and the unsoldered surface of the disc is flush with the open end of the plastic cup. A one inch piece of fine flexible plastic tubing is slipped down the wire and cemented into the $1/16$ inch hole, thereby providing some support for the lead at the electrode edge (Fig. 1,c). A tight, full circle press fit between the silver and the plastic cup is necessary for long term stability since leakage of the electrolyte into the electrode will generate intolerably high and uncorrectible bias potentials.

After hardening 24 hours, the exposed silver face is sanded smooth, using deionized water and fine water sandpaper, and plated by being made

the anode in a .07 Molar solution of KCl in deionized water. Batches of six such electrodes are usually plated simultaneously using a single silver cathode. A reasonably constant current of 0.5 milliamperes per electrode is supplied by a 45 volt battery (e.g., Eveready W-350) in series with a 20K ohm potentiometer and an ammeter. After plating for 30 minutes, the electrodes are shorted together for a few hours in .07 M KCl or NaCl. The resulting AgCl surface is generally coffee-plum in color. Neither nitric acid nor electrolytic etching prior to plating produced lower bias potentials or drift than did just careful sanding in deionized water. The completed electrode should not be cleaned with acetone or similar solvents since they may crack or soften the plastic. Deionized water is sufficient for most purposes.

Before use, the finished electrode unit is inserted partway into a collar of soft plastic having an I.D. of 3/8 inch and an O.D. of 5/8 inch (Fig. 1,d). The inside edge of the collar extends about 1/16 inch out from the base in the form of a slight lip. Such a band may be cut from ordinary plastic or vinyl tubing on a high speed lathe, or can be molded from silicon rubber. When completely assembled, the flanged end of the collar extends about 1/8 inch beyond the AgCl surface of the electrode, thus affording it some physical protection. This unit is filled with electrode paste and set on a felt corn pad (Dr. Scholl's No. 458) which has been applied to the skin (e.g., the finger) and half filled with paste (Fig. 2). The whole assembly is attached with tape and the lead wire secured to the proximal phalanx of the finger to reduce tension and strain on the electrode. In addition to minimizing movement and pressure artifacts, the corn pad provides a convenient means of limiting the spread of electrode paste and thereby defining the effective electrode

area. If a single active site is to be used, it is recommended that the skin under the inactive or reference electrode be drilled or sanded (Shackel, 1959; Venables and Sayer, 1963).

After use, the electrodes may be disassembled, rinsed off, and stored dry or, if they are to be used frequently, can be kept with the collars and paste undisturbed, shorted in a dilute salt solution. Prolonged soaking (e.g., several months) may hasten electrode leakage and shorten electrode life, however. Dry electrodes should stand shorted several hours in saline before use. If the AgCl surface should become damaged or contaminated, and the bias potentials high or unstable, the electrode may be disassembled, the silver face sanded smooth and replated, producing a new surface identical in quality to the original. This procedure may be repeated indefinitely, thereby extending considerably the range of usefulness as well as the normal functional life of the electrode.

Since potential differences within groups of electrodes plated together are smaller than those between sets, it is recommended (for SP measurement) that electrodes be prepared in groups of at least six and pairs with the lowest potentials selected for use. Bias potential and drift were measured with a Tektronix type 502 oscilloscope in two such sets of six electrodes (in .07 M KCl) for two hours. All possible combinations of two electrodes within each of the sets were recorded, giving a total of 30 different pairs (i.e., $2[6X5/2]$). Potentials, measured immediately after the electrodes were unshorted, ranged from 0.00 to 0.24 millivolts (mv) with a median of 0.08. Readings of drift taken after one hour yielded a range of 0.01 to 0.20 mv and a median of 0.05. Drift over the complete two hour period ranged from 0.01 to 0.27

mv with a median of 0.07. Since subsequent analysis has shown that the rate of drift is greatest during the first quarter hour after the electrodes have been unshorted, it is suggested that, for optimal stability, all electrode combinations be measured after a 15 minute drift period and pairs selected on the basis of the resulting potential differences. This kind of precision, of course, is not necessary for SC recording. The series resistance, at 10 microamperes, of a pair of these electrodes face-to-face in .07 M KCl is about 2 K ohms.

Temperature Effects

As Venables and Sayer (1963) have demonstrated, normally occurring temperature differences between electrodes of this type can produce artifactual voltages approaching 0.5 mv per degree centigrade. These authors have described an ingenious bridge circuit which automatically compensates for error voltage produced by non-isothermal electrodes in SP recording. Temperature sensors (thermistors mounted in grommets) placed on the skin alongside the electrodes, form two arms of a Wheatstone bridge. The electrodes described above, on the other hand, allow a convenient and sensitive method of detecting subtle temperature differences at the exact electrode site. A 3/64 inch hole is drilled diagonally through the wall of the plastic collar, entering the central core just below the face of the electrode. A small glass probe thermistor (e.g., Fenwal Electronics) can then be inserted directly into the paste area separating the electrode and the skin (Fig. 2), thus combining the two transducers into a single unit which may be used with the Venables and Sayer circuit. It should be noted, however, that while temperature compensation may be necessary for optimal accuracy

of SP measurement, in many instances in which room temperature is reasonably well controlled and a few minutes are allowed for electrode stabilization, such devices are not essential.

Electrolyte

Both the agar based electrode paste described by Venables and Sayer and a "Unibase" electrolyte have been used successfully for recording SP and SC with these electrodes over the past several years. The latter paste may be made as follows: dissolve 1.7 g. NaCl¹ in 100 ml. of distilled water and mix thoroughly with 300 ml. of Parke Davis Unibase. (An electric blender with non-metallic paddles is suitable.) Because the Unibase initially absorbs water and increases in volume slightly when mixed, the exact salt concentration after equilibrium has been reached is difficult to ascertain. Since the yield is a little over 400 ml., the NaCl molarity is approximately 0.07. The mixture is slightly less viscous than cold cream and may be conveniently stored in a flexible plastic mustard dispenser. This paste does not dry out quickly, nor will it readily turn rancid or stale. Strongly hypertonic electrode jellies designed to reduce skin resistance (e.g., Sanborn Redux) should not be used for electrodermal measurement.

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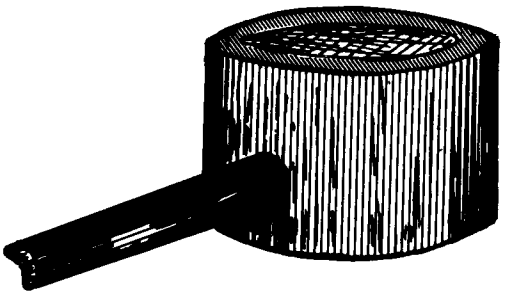
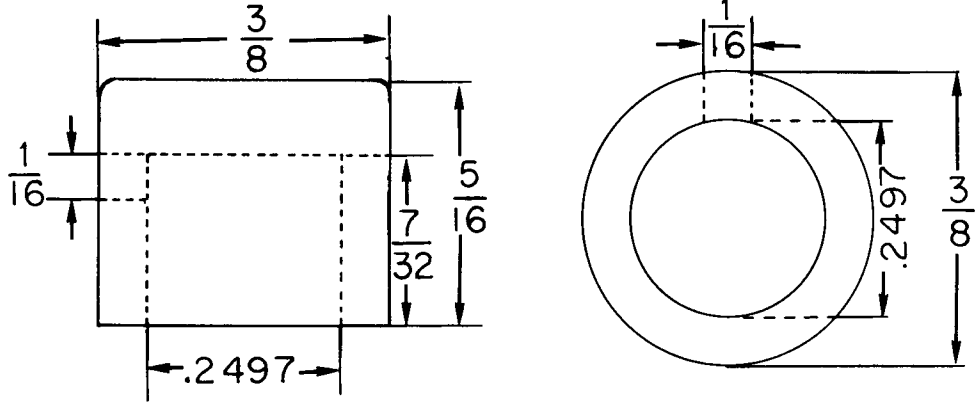
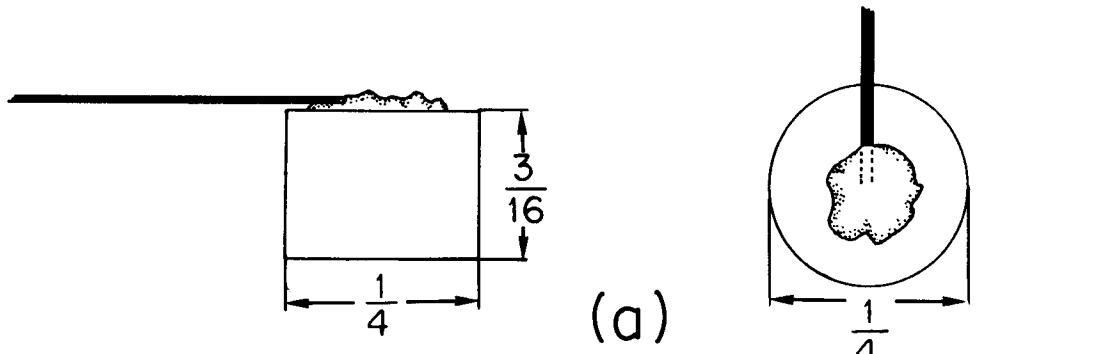
Footnotes

1. One may substitute 2.1 g. KCl if this salt is preferred or, for use with zinc electrodes, add 4.5 g. ZnSO_4 instead.

Figures

Figure 1. Construction of the Ag-AgCl electrode. (a) silver disc and lead wire. (b) plastic cup. (c) electrode unit. (d) soft plastic collar.

Figure 2. Mounted electrode assembly.



(c)

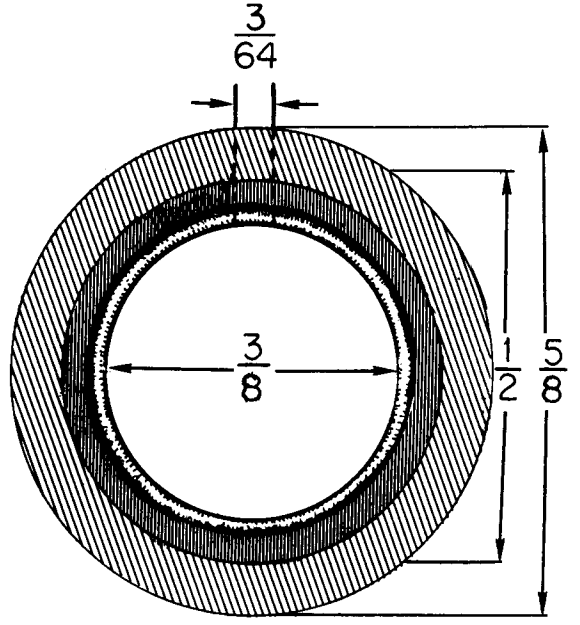
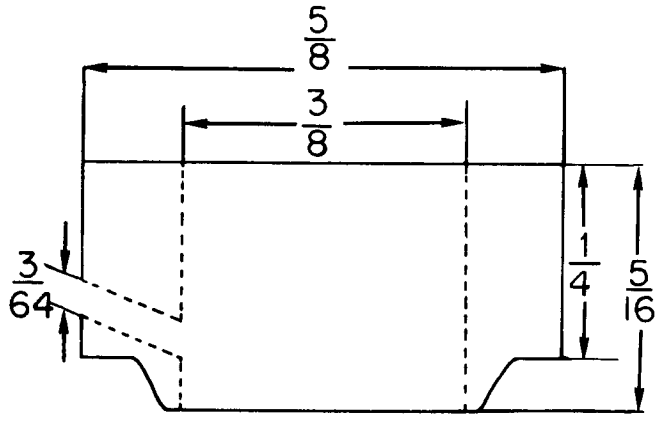


Figure 1

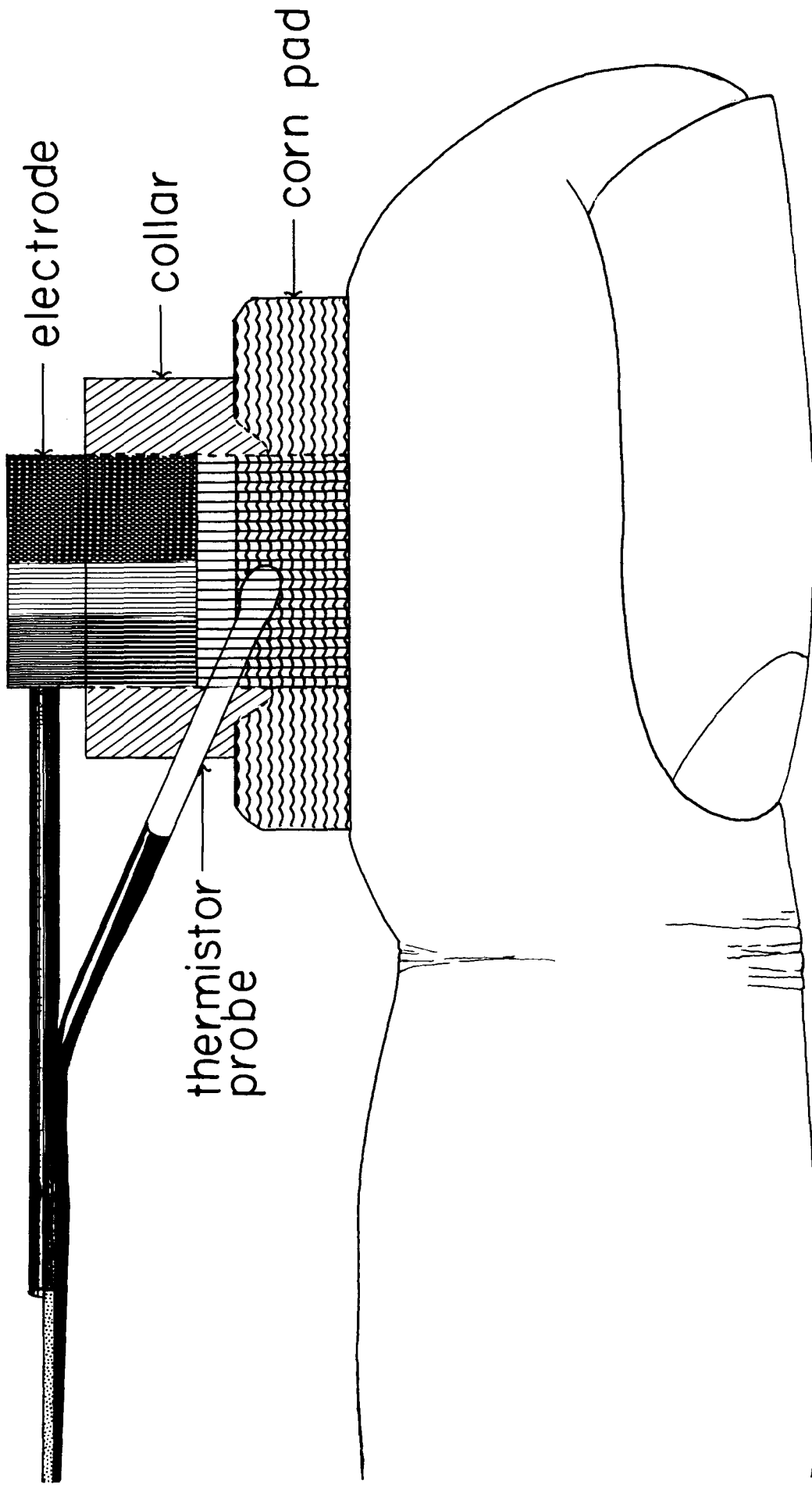


Figure 2