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REVIEW OF NASA-MSC ELECTROENCEPHALOGRAM AND ELECTROCARDIOGRAM ELECTRODE SYSTEMS INCLUDING APPLICATION TECHNIQUES

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ABSTRACT

A silver/silver chloride/gelatinate matrix electrode in conjunction with a specially prepared electrolytic paste was developed at the National Aeronautics and Space Administration Manned Spacecraft Center in an effort to enhance readings of space-flight electroencephalogram, electrocardiogram, and respiration monitoring systems.

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SUMMARY

The special conditions of space-flight monitoring require data quality levels unobtainable with conventional electroencephalogram and electrocardiogram devices. Researchers at the National Aeronautics and Space Administration Manned Spacecraft Center have directed their efforts toward developing an electrode system (that is, electrode, electrolytic paste, housing, integument, and harness assembly) of adequate responsiveness and endurance. The subsequently developed system included an electrode consisting of a silver/silver chloride/gelatinate matrix imbedded in a methylmethacrylate housing. Data quality was maximized by using a specially prepared electrode paste composed of concentrated Ringer's solution as the electrolyte, hydroxyethylcellulose and polyvinylpyrrolidone as the vehicle, and methyl p- and propyl p-hydroxybenzoate as preservatives. Preparation of the integument prior to electroencephalogram electrode application (such as by decornification) helped to eliminate artifact. The total system proved to be remarkably noise free.

INTRODUCTION

Techniques for monitoring the psychophysiological activities of men in space have been of prime importance since the beginning of manned space flights. Conventional instrumentation and techniques, although suitable for short-term or clinical use, were inadequate for long-duration flights and experiments.

It became necessary to investigate ways of improving and optimizing the instrumentation. Since the electrode was the weakest link, every effort was exerted to maximize verifact and minimize artifact in these electrodes. However, the problem could not be solved by investigating the electrode alone. The electrode, the contact medium (that is, electrolyte, vehicle, and preservatives), and the integument had to be considered as a system.

The research described in this paper was conducted in an effort to develop an optimum electrode/integument system that meets certain specific requirements such as low cell potential, stability, and reversibility. This system had to prevent the buildup of undesirable ion species (poisoning) on the electrode surface. Skin-electrode junction resistance and skin-electrode potential had to be minimized, stabilized, and maintained in the equilibrated state. Furthermore, the electrode/integument system had to be relatively comfortable (with minimal skin irritation and bacterial growth), easily maintained, and of long attachment duration (ref. 1).

This paper describes the development and evaluation of such electrode/integument systems. Detailed attention is given to the respective electrode, electrolytic paste, harness assembly, and integument subsystems. Finally, the description of the components is followed by a step-by-step presentation of application procedures.

ELECTRODE DESCRIPTION

In the electrodes (wet electrodes) developed at the Manned Spacecraft Center (MSC), direct metal-to-skin contact was eliminated by substituting a compatible electrolyte gel to pass the current between the electrode and the skin. A silver/silver chloride material, because of its low potential, stability, and longevity, was considered the most suitable for electrode development (refs. 2 and 3), although other metal/metal salts were considered. A previous paper (ref. 4) presented an introductory effort in this area.

General Considerations

Figure 1 depicts the various modified project electrodes. The Project Mercury housing was originally molded from silicone rubber to form a 1-3/8- inch flange diameter and a 5/8-inch electrode area. However, experiments demonstrated that a flexible housing contributed to electrode artifact and wear. Subsequent housings, therefore, were rigid with a smaller flange and were made of methylmethacrylate (fig. 2).

The housing concept in most wet electrode systems is similar, differing only in housing material and configuration. The housing in the MSC systems consists of a cup designed to support the electrode above the skin. Epoxy resin seals the electrode in place and insulates the wire and solder joint from the paste, thus reducing motion artifact and electrochemical noise.

The inside diameter of the housing limits the effective electrode contact area which dictates the resistance on the intact skin. The contact area size is a compromise and conforms to various electrical factors such as the inverse variation of area with current density and resistance.

Chronological Development

Modified Project Mercury anodized silver/silver chloride electrode. - The first silver/silver chloride electrode developed during Project Mercury was a perforated disk fabricated from 99. 9-percent silver. A lead was soldered to the far side of the silver disk as shown in figure 1. The rosin soldering flux was removed from the solder joint with alcohol. A light coat of epoxy was painted over the joint to prevent exposure of any metal other than silver. The lead was tied down to the near side of the disk with a fine nylon suture and coated with cement to maintain the knot.

The disk was polished bright, then washed in acetone and in deionized water, and anodized for 20 minutes at a current density of 3 mA/cm^2 in 0.1 N sodium chloride (NaCl) using a silver cathode. A velvet-like, even coating of silver chloride was deposited.

Gelatin coated, anodized silver/silver chloride/gelatinate membrane electrodes. - Improvements on the basic silver/silver chloride electrode were made for use in the Gemini Program systems. These electrodes included a gelatin to minimize electrode "poisoning." They were fabricated by anodizing a silver electrode in a 1.0 N aqueous solution of potassium chloride (KCl) containing 0. 1 percent "A" gelatin (ref. 4), using a platinum cathode of adequate size to provide sufficient throwing power (fig. 3). The "A" gelatin is an acid-treated precursor gelatin with an isoelectric point at a pH between 7 and 8. In this neutral range, the gelatin molecule has a positive charge; KCl in solution with the gelatin reverses the charge, and the resulting negatively charged gelatin molecules are attracted to the anode. A firmly bound silver/silver chloride/gelatinate matrix is the result.

The two types of Gemini Program electrodes differ only in size. The electroencephalogram (EEG) electrode (fig. 4) has a total outside diameter of thirteen-sixteenths inch and a skin contact area of 1 cm^2. The electrocardiogram (ECG) skin contact area is 2 cm^2 and has a total outside diameter of 1-1/8 inch.

SUPPORTING COMPONENTS

Electrode Paste

The electrodes may be used with any electrolytic paste which contains chloride ions; however, to allow repeated long-term application, a special nonirritating paste containing no abrasive was developed at MSC (ref. 5).

It was first thought that a modified bentonite compound containing 30 percent calcium chloride ($CaCl_2$) would be suitable as the vehicle-electrolyte. A 48-hour test had shown no resultant irritation using this combination (ref. 6). However, one of the Mercury astronauts developed an irritation from the $CaCl_2$ (ref. 7), and Ringer's solution was substituted as the electrolyte.

Carboxypolymethylene replaced bentonite as the vehicle. The paste then consisted of 5 percent carboxypolymethylene neutralized with 3 M sodium hydroxide (NaOH), Ringer's solution concentrated tenfold (×10), and preservatives. It was evaluated on 13 subjects, 12 male and 1 female, during a 24-hour period. Anodized silver/silver chloride ECG electrodes filled with the paste were attached to each subject in the midaxillary line at the xiphoid process. The direct-current resistance between electrodes was measured with a vacuum tube voltmeter (VTVM) at the beginning, again after 1 or 2 hours, and at the end of the test period. The results, although indicating low resistance values, were not essentially valid but were a measure of the lowering of resistance by primary mechanical irritation (that is, by rubbing), an extremely variable

Carboxypolymethylene proved unsuitable as a vehicle. It reacted with divalent cations in the solution, cross linking and causing lumping in the paste. It also freed an excess of hydrogen ions to create an acid solution. Since a neutral, unbuffered pH was considered the best vehicle choice (ref. 8), hydroxyethylcellulose was substituted.

The electrolyte portion of the paste is essentially the same as Ringer's solution concentrated tenfold (×10), with polyvinylpyrrolidone (PVP) and hydroxyethylcellulose as a vehicle for the paste. Added as preservatives are 0.9 percent methyl p- and 0.45 percent propyl p-hydroxybenzoate.

One liter of paste may be prepared from the following constituents:

1. Methyl p-hydroxybenzoate . . . . 0.9 gram
2. Propyl p-hydroxybenzoate . . . . 0.45 gram
3. Hydroxyethylcellulose . . . . 110 grams
4. PVP . . . . 35 grams
5. NaCl . . . . 90 grams
6. $CaCl_2$ . . . . 3.3 grams
7. KCl . . . . 3.1 grams
8. Deionized water . . . . 1 liter

All of the reagents used must be of analytic reagent grade or higher purity. Preparation is as follows: The benzoates are mixed into 1 liter of deionized water; salts are added; then the vehicles (that is, first the PVP, then the hydroxyethylcellulose) are blended in slowly. All constituents should be thoroughly mixed; food coloring is added at this point. The compound should be adjusted to a pH of 7.0 ± 0.1 using 6 N NaOH and left to stand, covered, overnight. The paste is ready for use after deaeration for 20 minutes at a reduced pressure.

Polyvinylpyrrolidone was added to the Ringer's solution with hydroxyethylcellulose paste to improve its consistency. This electrode paste produces reduction in skin resistance with minimal trauma to the skin, which is the compromise involved.

However, it must not be used to measure galvanic skin response (GSR), skin resistance, or skin potential, as it is designed to reduce skin resistance. A paste suitable for GSR differs by containing 60 grams of hydroxyethylcellulose, no PVP, and 5.8 grams of NaCl instead of the Ringer's solution. The benzoates are included as preservatives. This provides a 0.1 N NaCl electrolyte compatible with GSR-type measurements and normal skin exudate.

Harness Assembly

The EEG harness assembly (fig. 4) consists of two major components: the single conductor American Wire Gauge (AWG) 26 with gold-plate-shielded copper wires and with Mylene insulation molded in a silicone harness, and the electrodes. Two harnesses are required for the ECG (fig. 2); one for the sternal electrodes, the other for axillary electrodes. The conductor is fabricated from 66 strands of AWG 44 copper wire to make a composite of AWG 26. This wire has a polyvinylchloride (PVC) insulation, a silver-plated shield, and a PVC jacket. The connectors are epoxy potted. The sternal electrode harness input has two signal electrodes and a ground electrode; however, a ground electrode is no longer used. The axillary electrode harness has two electrodes and an impendance pneumograph jumper which provides parallel wiring of the input connectors to the ECG and the impendance pneumograph signal conditioners.

Integument

Intact sites on the integument have a high resistance which drops off in value for about 2 hours until a relatively stable resistance level is reached with the electrodes and paste described above. However, potential between sites is a basic source of difficulty rather than resistance. Since low potential indicates low resistance (approximately 1 to 2 mV potential to have approximately 1 kilohm resistance) and since both potential and resistance are mediated by the same membranes, a low-resistance electrode will be relatively noise free.

Treatment of the skin to lower resistance for EEG recordings has been limited in actual practice to decornification. The Day-Rickles modification of Shackel's technique (ref. 9) uses a high-speed electric rotary tool (20 000 cps) and a sterile no. 6 steel dental burr.

Decornification is carried out as follows: The skin is first gently swabbed with benzalkonium chloride or another biocide for disinfection and then swabbed with acetone to degrease and desiccate. A small circle (1/8-inch diameter) is marked on the skin. Three to six very light passes are made over the site with the electric rotary tool. The no. 6 dental burr is coarse enough that clogging does not occur. The actual contact should be extremely short and very light in pressure to avoid thermal irritation. If properly done, no pain or bleeding occurs because the material removed is only the dead scaly cells of the upper layers of the stratum corneum. A few practice trials will suffice to master the technique. One or two trials to draw blood will demonstrate how little material need be removed for adequate preparation. The value of this preparation is twofold; it provides both low skin resistance and low skin potential, and it establishes immediate equilibrium requiring no waiting period. It also serves as an ideal reference site for GSR measurements.

The test for sufficient preparation consists of a light touch with an acetone sponge which will cause a slight stinging sensation if the preparation is complete. Care should be taken not to use too much acetone because the cold sensation will obscure the stinging.

Use of the multimeter to measure resistance of skin-electrode systems is discouraged because the relatively high current density is extremely detrimental to the silver chloride coating. However, the following methods are recommended: Connect a 10-microampere constant-current source and a high-impedance VTVM, and determine the resistance using Ohm's law. An alternative method is to insert sufficient resistance (decade resistance box) in parallel with the subject to decrease the signal by one-half and then to read the skin resistance from the decade resistance box.

APPLICATION PROCEDURES

Electroencephalogram Electrode Application Procedures

After carefully protecting the neck area of the subject against falling hair particles, the electrode site is first shaved to 1-1/8-inch diameter and then a depilatory is applied (ref. 10). After 20 minutes, a moistened tongue depressor and soap and water are used to remove the depilatory. The subject should then be permitted to shower and shampoo.

The site is cleansed with benzalkonium chloride, then with a reagent-grade acetone, glass bottled, taking care to avoid contact with the eyes or ears.

Decornification is accomplished as previously described. The electrode housing is filled to just below flange level with electrode paste. Care should be exercised to avoid contact with the flange. A light coat of 2-methylcyanoacrylate is applied to the flange, and the electrode is placed on the site. However, too much adhesive will occlude the electrode, while underapplication may result in electrode-paste leakage; therefore, these conditions should be examined.

The electrode is removed by placing a thumbnail under the flange and quickly separating the electrode from the scalp. The area is then cleansed with benzalkonium chloride, and a lanolin-type lotion is applied.

Electrocardiogram Application Procedures

The ECG electrode-application technique is similar to that used for the EEG electrode. The entire area is swabbed with a biocide such as benzalkonium chloride. If necessary, hair is removed by shaving, followed by the application of a depilatory. The depilatory is removed by washing with soap and water; then the area is reswabbed.

A double-adhesive disk with protective cover in place is set on the electrode flange, and the electrode reservoir is filled with electrolyte to a height slightly below the flange level (fig. 5). A slight negative meniscus is ideal; however, it is important not to overfill the reservoir.

Next, the skin is swabbed gently three times (without rubbing) with copious amounts of glass-bottled acetone of reagent grade. The subject should be protected during this procedure by placing a towel below the site. The skin is then allowed to air dry.

The protective covering is removed from the adhesive disk, and the electrode is applied to the skin (fig. 6) by pressing evenly around the housing. If electrode paste has leaked at this point, the electrode should be replaced. The entire electrode is then covered with a 3-inch disk of surgical tape (ref. 11). Skin will be visible through the tape if the tape is properly applied.

When the tape and electrode are removed, the area should be cleansed thoroughly with benzalkonium chloride and a lanolin-type skin lotion applied.

The electrode itself should be separated from the adhesive disk and then cleansed with a soft brush in running warm water, followed by a cleansing in deionized or distilled water.

Similar Application of Blood-Pressure Microphone and Phonocardiogram Transducer

The application of the blood-pressure microphone and phonocardiogram (PCG) transducer is similar in technique to that of the EEG and ECG electrodes. A double-adhesive disk with protective covering in place is attached to the microphone or PCG face. No electrode paste is used. The skin is prepared with acetone as before. After removing the protective covering, the microphone or PCG is pressed on the skin and covered with a 3-inch disk of surgical tape.

When removing the microphone, care must be exercised to avoid diaphragm damage. The skin is cleaned in the same manner as the ECG electrode.

CONCLUSIONS

The silver/silver chloride membrane electrodes are more artifact free than conventional electrocardiogram and electroencephalogram electrodes. Long-term-duration tests show, if the application procedure is meticulously followed, that the electrodes will remain in place, providing a high-quality signal for long periods. Dermatological and microbiological tests indicate that the paste and electrodes are nonirritating and cause insignificant microbial proliferation during 14-day periods.

Manned Spacecraft Center
National Aeronautics and Space Administration
Houston, Texas, November 8, 1967
914-50-80-03-72

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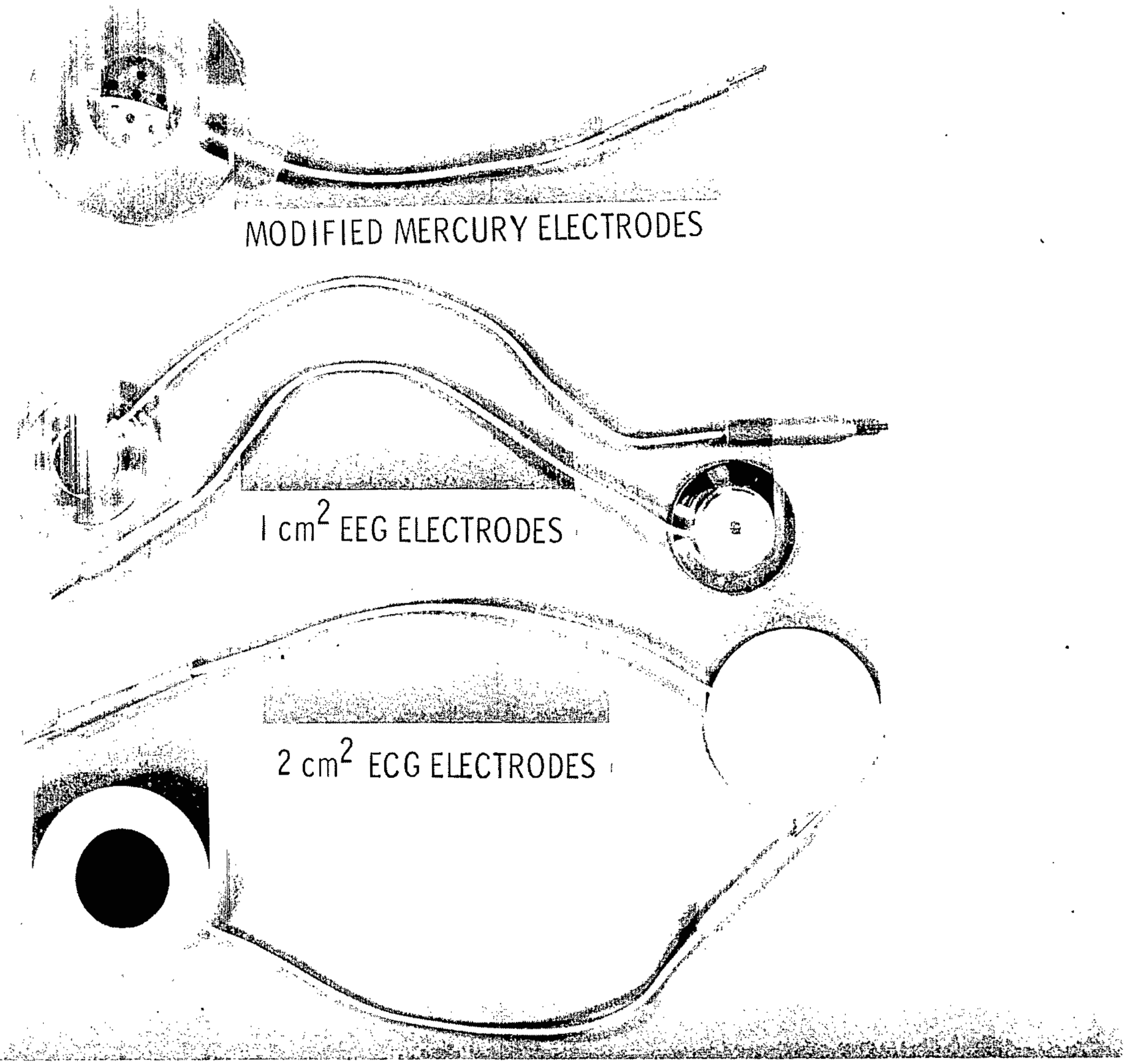

Figure 1. - Modified Mercury electrodes.

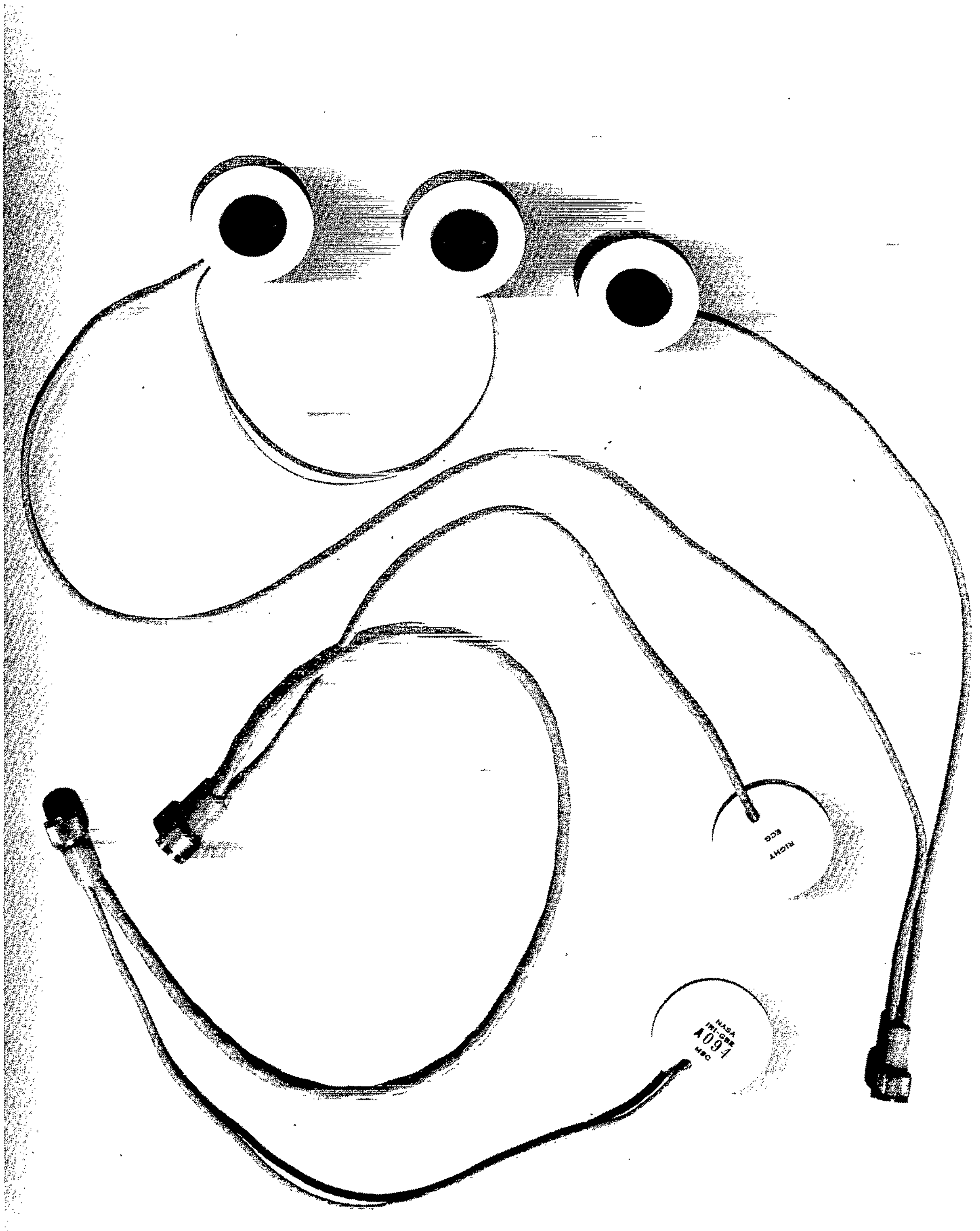

Figure 2. - Project Gemini flight electrodes, with methylmethacrylate housings.

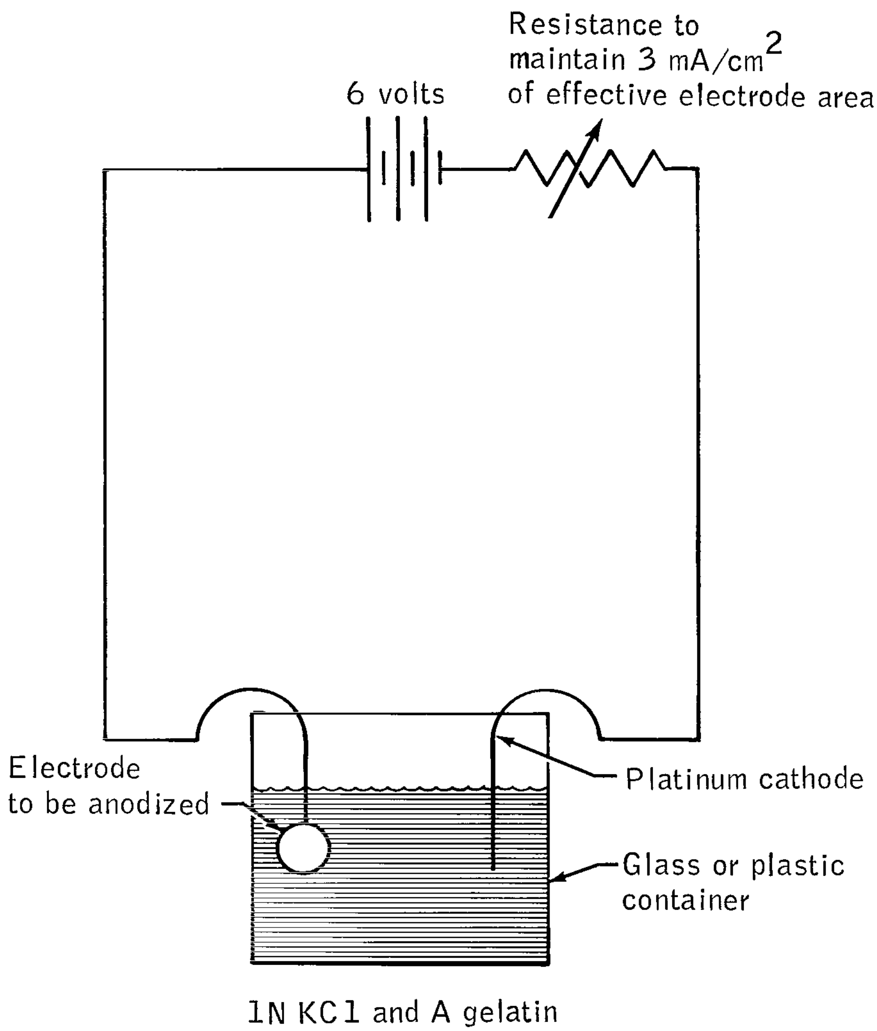

Figure 3. - Anodizing apparatus.

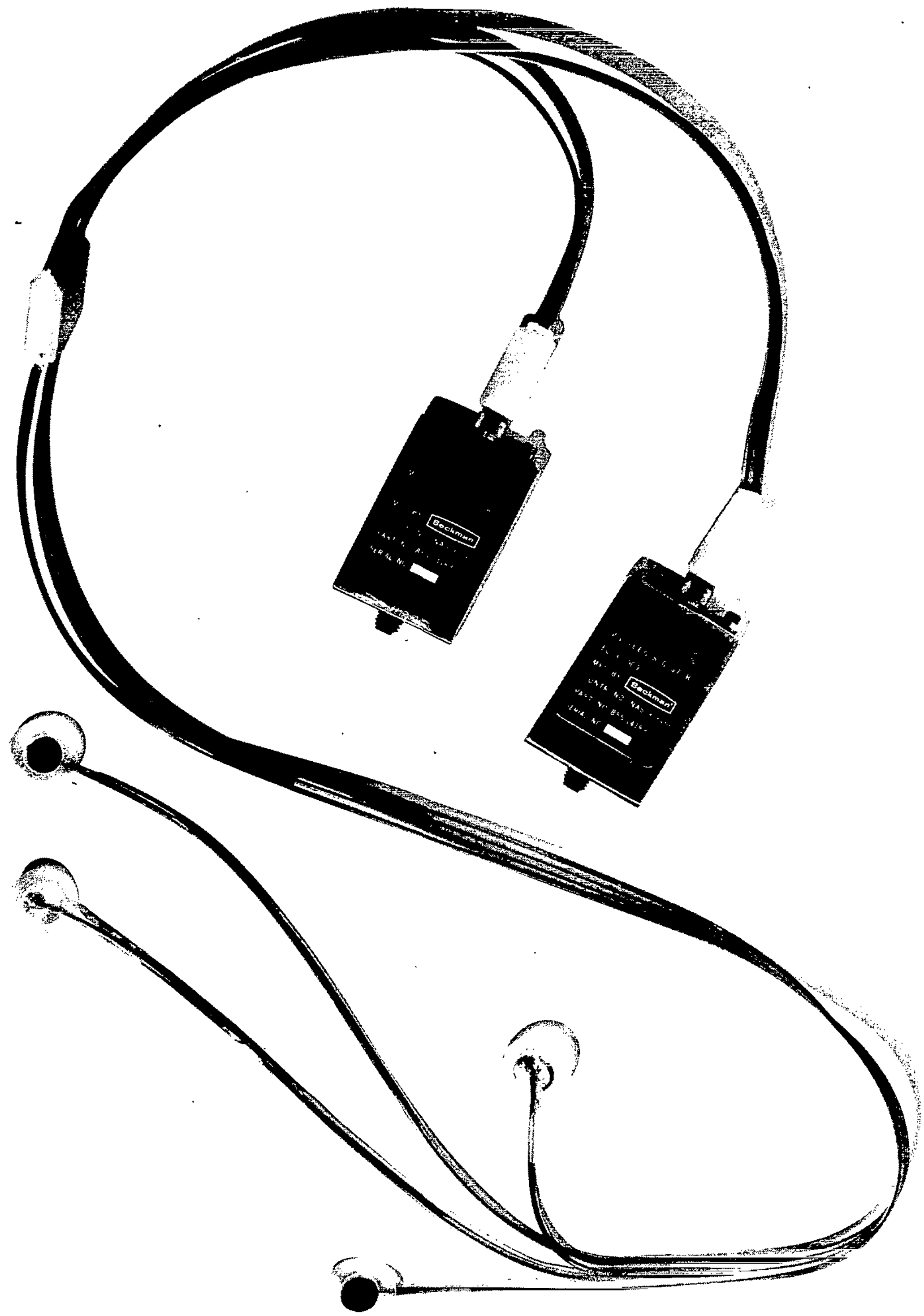

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Figure 4. - Electroencephalogram electrodes and signal conditioners.

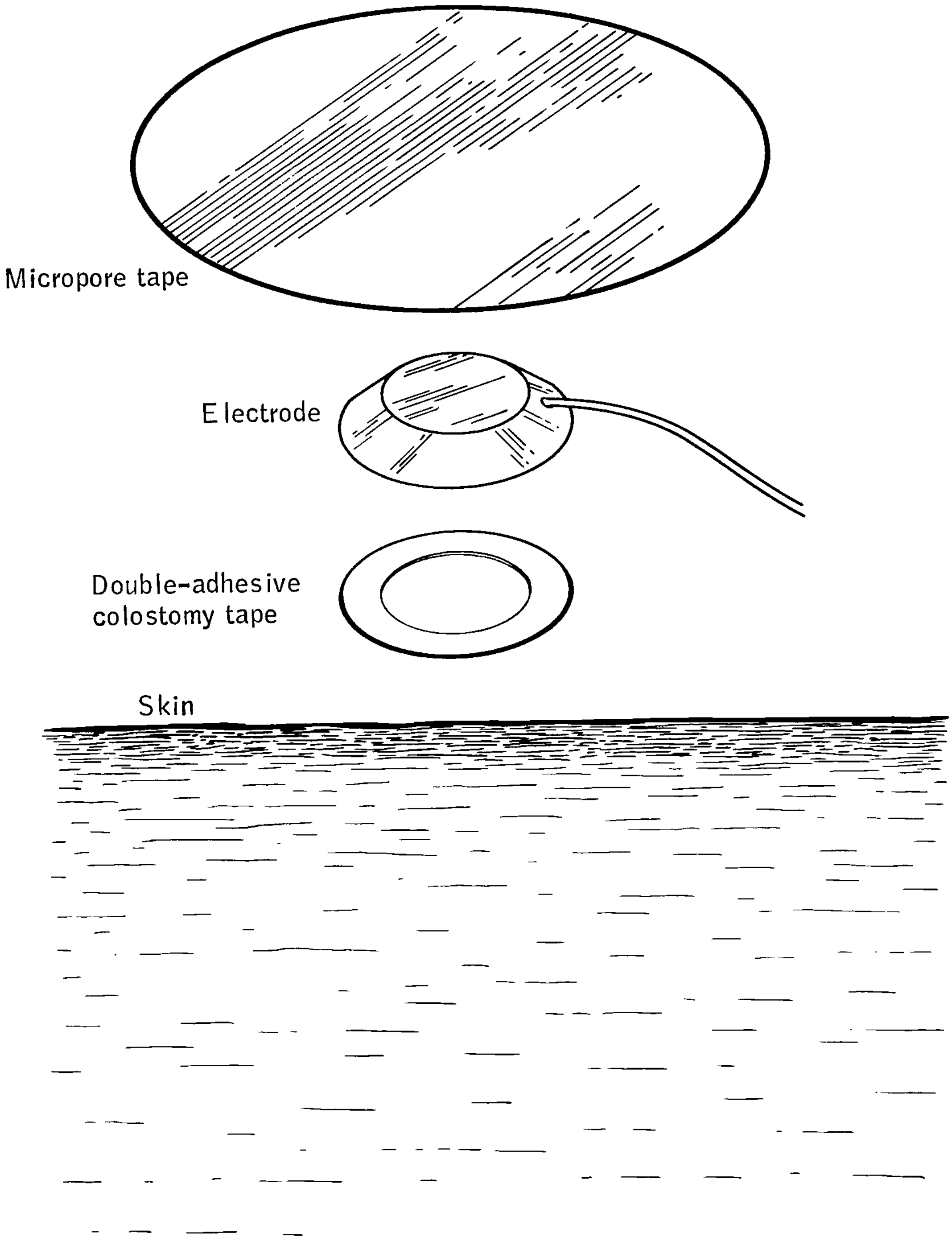

Figure 5. - Sketch of electrode/integument system.

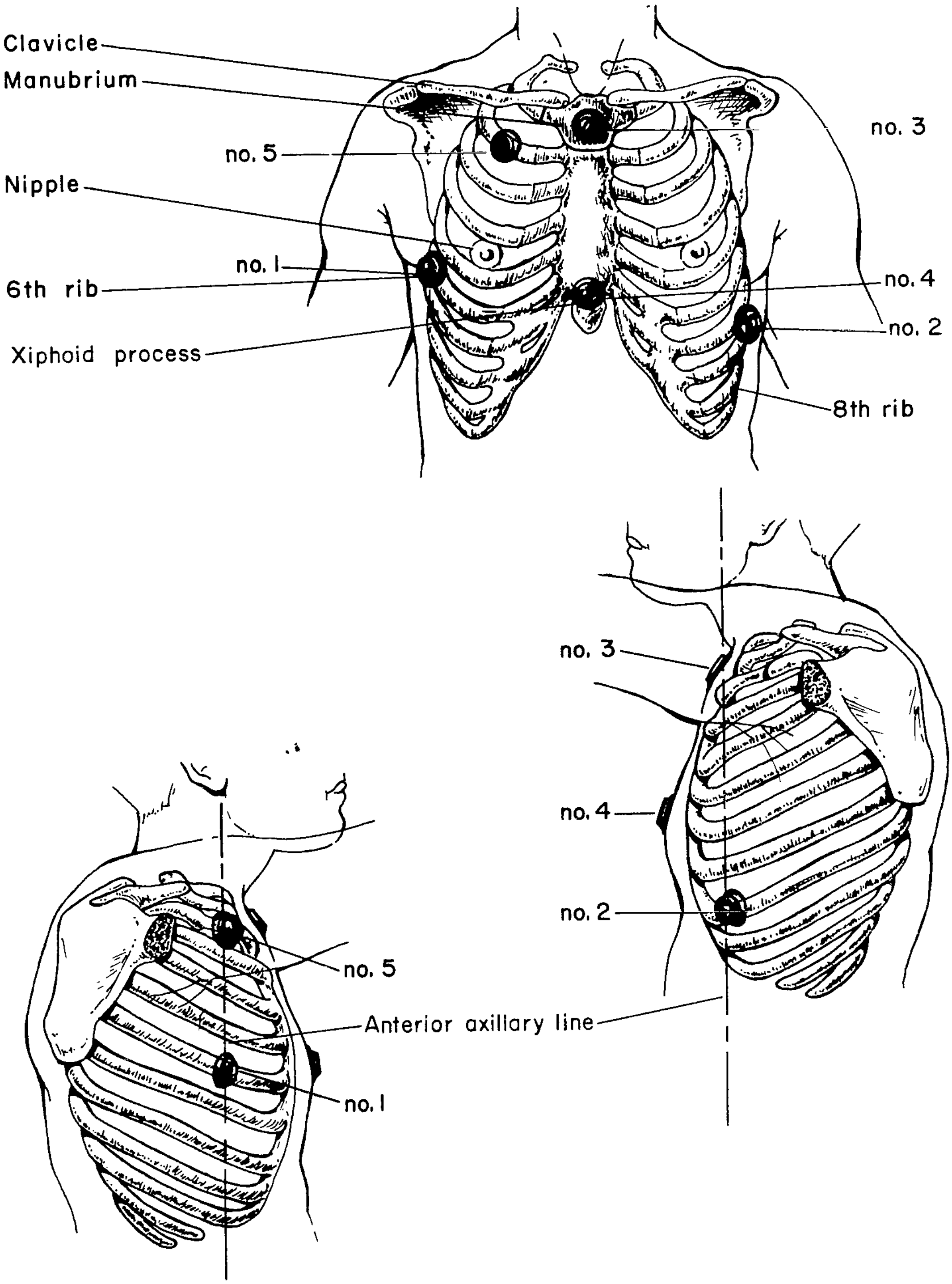

Figure 6. - Gemini ECG electrode placement: front, right, and left lateral views.

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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