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A LONG-TERM ELECTRODE SYSTEM SUITABLE FOR ECG AND IMPEDANCE PNEUMOGRAPHY

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INTRODUCTION

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The problem of recording electrocardiograms on an active subject has long plagued investigators as well as clinicians. The d-c potential changes which cause baseline drift and blocking of amplifiers have caused considerable annoyance. The electrode described in this paper is a modification of the NASA Manned Spacecraft Center (MSC) Mercury ECG flight electrode.

At the inception of the Project Mercury program, a decision was made to telemeter two electrocardiogram leads, one channel of respiration and one channel of body temperature.

In later flights, two additional electrodes were used in order to obtain a better measure of respiration by means of an impedance pneumograph.

The present electrode system was evolved as a result of skin irritation after long and repeated usage of electrodes as well as noise caused by the electrodes while they were being used on active subjects. Data have been collected on long-term application of these electrodes for periods of at least 96 hours.

ELECTRODE DESCRIPTION

At first, stainless steel mesh was utilized because of its resistance to corrosion. (See refs. 1-3.) This mesh, however, proved to be the cause of

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considerable motion artifact caused by electrochemical non-reversibility. (See ref. 4.) The unprotected compound metal junction of the solder joint was also a source of spurious potentials. The present silver/silver chloride electrode system eliminates these undesirable characteristics and provides stable low-noise transduction of bioelectric potentials. The present electrode (Figure 1) is fabricated from jewelers fine grade silver sheet 0.030 inch thick. Discs measuring 0.75 inch in diameter are punched from the sheet stock and 8 holes are drilled with a no. 53 drill to provide passage of electrode paste. Two holes are drilled with a no. 58 drill near the edge of the disc to provide a tiedown to anchor the lead wire.

The disc is then sanded until bright and a no. 24 AWG polyvinylchloride insulated wire is soldered to the far side of the disc. The flux is then removed from the solder joint and a coat of epoxy resin is applied to insulate the compound metal junction. After the epoxy has been well cured, the disc is degreased and washed thoroughly with deionized water. The disc is then placed in a cell with a silver cathode in 0.10 normal sodium chloride (Figure 2) and anodized for 20 minutes at a current density of 3 milliamperes per square centimeter, based on the total surface of the active electrode area.[1] A smooth, even, velvet-like coat of silver chloride should be produced. This surface must not be touched with the fingers or any metal. The lead wire is then dressed flat across the disc and secured with a fine nylon suture to provide strain relief. A drop of cement is applied to maintain the knot.

The electrode housing is injection molded from Dow-Corning S-6015-A silicone rubber. The housing is designed so that the electrode disc is supported above

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[1] An area of 3 cm^2 was used to allow for the area consumed by the holes and insulated solder joint.

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the skin by a circular groove. The electrode is carefully placed in the housing and the lead wire brought out through the strain relief. (Clean cotton gloves or surgical gloves are convenient for handling the electrode surface.)

The electrodes are tested in sets for potential with a high impedance millivoltmeter in 0.10 normal sodium chloride. If the potential difference is in excess of 1 millivolt, the electrode is reanodized or discarded. After measuring the potential, the electrodes are washed in deionized water and air dried. They may be stored for indefinite periods if there is no contamination of the silver/silver chloride surface.

It is important that all reagents be of analytic grade and that the water be either deionized or double-glass distilled.

Electrodes fabricated in the manner described in the preceding paragraphs may be reused repeatedly. During their use, the reversibility of the electrode undergoes deterioration and the potential rises. When it rises above approximately 5 millivolts, the electrodes become noisy and should be cleaned and reanodized.

APPLICATION PROCEDURE

The method of application of the NASA-MSC electrode is simple and rapid (Figure 3) and can be applied in 3 minutes or less by an experienced technician.

The Stomaseal[1] tape with its protective covering remaining intact is first applied to the flange. The flange side of the electrode is then filled with electrode paste. (See page 5 for a more complete discussion.) The skin is

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[1] Scotch No. 1500 Stomaseal (Colostomy) Tape.

lightly swabbed with acetone to remove skin oils. The electrode is firmly pressed to the skin, usually along the mid-axillary line and at the sixth intercostal space. The outer compartment of the electrode is then filled to just below the top. A 1-inch square of Mystic[2] tape is applied to close the opening. If the electrode is overfilled, a leak is likely to develop at this point. Both the flange and the outer opening of the housing must be clean and dry to adhere. Micropore tape[3] is applied to cover the entire electrode to prevent rubbing against the arms or clothing.

After removing the electrode, the skin is cleansed with Zepherin chloride and an antiseptic skin lotion such as Spectrum's lab-lotion is applied. In over 3 years' use this procedure has prevented irritation or infection.

If extremely low resistance is required, e.g., 1 to 5 kilohms, one of two methods may be used to prepare the skin before electrode application. Rubbing the skin until it is erythrodermic will drop resistance but this method is irritating and occasionally causes infection. A second method is decornification or skin drilling. This technique is fast, easy, and reliable. (See ref. 5.) Both methods will produce a low resistance of 1 to 5 kilohms which is usually maintained for about 48 hours. A high-speed rotary tool (20,000 rpm) and a no. 6 steel dental burr have been found effective for this purpose.

Since the resistance of the skin is approximately inversely proportional to the electrode area, a standardized 2 cm^2 electrode is used because of input impedance and other amplifier considerations. When better signal conditioners

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[2]Mystic Silicone Tape No. 7010.

[3]Scotch Micropore Surgical Tape No. 530.

are developed, the electrode area and housing size will be reduced, however, this electrode will perform satisfactorily with practically any available amplifier.

ELECTRODE PASTE

This electrode can be used with any electrode paste which contains chloride ions; however, to allow repeated long-term applications necessary to the MSC programs, a special non-irritating paste was developed which has been successfully used for periods exceeding 1 week.

It was discovered that an electrode paste with the same ionic content as ten times that of Mamallian Ringer's solution seemed to provide a relatively low-resistance coupled with minimal skin irritation for periods in excess of 1 week. The formulation of the current electrode paste for ECG and impedance pneumography is presented in the following paragraphs. This paste seems to be relatively non-irritating, non-sensitizing, and has a long shelf life. It must be emphasized that this paste must not be used for galvanic skin response, skin resistance, or skin potential measurement since it is intended to reduce skin resistance (ref. 6).

The following is a formula for preparing electrode paste:

1. Ingredients for 1 liter

   a. 1 gm methyl-p-hydroxybenzoate } Preservatives

   b. 1 gm propyl-p-hydroxybenzoate }

   c. 80 gm hydroxyethylcellulose--more can be used if thicker consistency is desired. (Natrosol 250 GR Hercules Powder Company)

   d. 35 gm polyvinylpyrrolidone K-90 (General Aniline Corp.)

   e. 90 gm sodium chloride

f. 3.1 gm potassium chloride

g. 3.3 gm calcium chloride

h. All reagents must be analytic grade

i. 1 liter deionized water

2. Blending Process

a. Add benzoates to 1 liter of deionized water and blend by using a mixer with plastic coated beaters and a glass or plastic container. (An electric beater-type mixer is highly satisfactory for this purpose.)

b. Add salts and blend.

c. Add polyvinylpyrrolidone to water and blend slowly.

d. Add hydroxyethylcellulose and blend slowly.

e. Blend thoroughly and add food coloring to suit.

f. Adjust pH to 7.0 ±0.1 using pH meter; let stand overnight and recheck pH.

3. Storage

a. Use plastic tubes or containers.

b. No metal should come in contact with paste.

LONG-TERM ELECTRODE TESTS

In addition to numerous short-term tests (up to 48 hours) performed during the development of the electrode system, a series of tests of longer duration were carried out. A description of the most extensive of these tests follows. A group of 21 white, male prisoners, aged from 19 to 52, was made available through the courtesy of the Texas Department of Correction at the Huntsville State Prison. The subjects were selected on the basis of general good health and no history of dermatitis. The test involved no changes in daily routine for the subjects, who continued their routine jobs, engaged in active sports, and took daily showers. No special instruction was given to the subjects except that the electrodes could be removed if they became uncomfortable. Two electrodes were applied, one along each mid-axillary line at the seventh intercostal space. The only skin preparation was a gentle swabbing of the skin with acetone to remove skin oils. The d-c resistance of each electrode was measured against a freshly applied drilled reference electrode on the upper arm immediately after application and repeated each 24 hours for the 96-hour period. A high-impedance voltmeter was used in conjunction with a 10-microampere constant current source. The resistance was then calculated by using Ohm's Law.

The results of the test are summarized in Table I and presented in Table II.

TABLE I.- SUMMARY OF ELECTRODE RESISTANCE

Day	Electrodes remaining	Range, kilohms	Mean, kilohms	Median, kilohms	Number greater than 25 kilohms
0	42	12-250	62.5	30	23
1	42	1-18	12.6	12	0
2	40	3-27	13.8	12	3
3	35	3-40	14.1	11	4
4	33	4-250	21.5	9.5	2

As will be noted, the resistance on Day Zero is quite high. The explanation for this high resistance is that the measurement was made before sufficient time had elapsed to permit the electrode paste and skin to reach equilibrium which generally requires 1 to 2 hours. If the skin is prepared by skin drilling or rubbing, the reduction in resistance is almost immediate. This method, however, is not recommended for long-term use since any irritation of the skin is uncomfortable and occasionally infections result. Also, the skin drilling and rubbing seems to be limited to approximately 48 hours because of skin regeneration.

On the days following Day Zero, the resistance decreased to very satisfactory levels and remained there with only two exceptions for the remainder of the test. Several electrodes were impossible to measure because of broken or faulty wires. This problem has since been solved by the use of the nylon suture strain relief described.

Upon removal of the electrodes, an examination of the sites revealed no skin irritation under the electrode paste, however, some mild irritation was observed under the electrode housing and under the Micropore tape. This irritation was believed to be largely the result of mechanical irritation and is uncommon in the relatively inactive subject.

It will be noted that of the 42 electrodes applied only 9 failed to remain attached the entire time. It would be expected that in normal usage (no violent exercise) that few, if any, of the electrodes would be lost for this 96-hour period or even longer periods.

Because of the inherent difficulties involved in long-term testing of large numbers of subjects, no further tests have been carried out to date. It is felt that the long-term potential of this electrode system has not been fully realized and that tests of longer duration are indicated to establish the useful life of this electrode system.

SUMMARY

A description is given of an electrode system for sensing bioelectric potentials. This system is an extension of the Project Mercury

electrocardiograph-impedance pneumograph electrode. This is a low noise electrode for use on active subjects and has been used for periods up to 96 hours.

REFERENCES

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TABLE II.- ELECTRODE RESISTANCE IN KILOHMS

Subject	Position of electrode	Day				
		0	1	2	3	4
1	Left	110	10	8	6	4
	Right	100	15	13	3	2.5
2	Left	15	6.5	10	26	Open
	Right	15	6	6	9	150
3	Left	150	20	7	9	7
	Right	150	8	5	7	5
4	Right	75	10	20	40	18
	Left	65	20	27	Off	Off
5	Left	25	20	10	10	6
	Right	25	8	30	30	25
6	Left	25	6	12	18	22
	Right	25	18	9	4.5	4
7	Left	28	9	20	12	20
	Right	30	4	12	10	15
8	Left	20	1	3	4	15
	Right	12	12	17	18	15
9	Left	25	12	9	35	Off
	Right	25	20	10	Off	Off
10	Left	140	20	7	8	3
	Right	150	10	13	Off	Off
11	Left	18	8	8	12	Open
	Right	20	8	10	9	8
12	Left	25	14	6	5	15
	Right	40	11	15	11	Off
13	Left	150	14	25	25	22
	Right	250	10	40	Off	Off

TABLE II.- ELECTRODE RESISTANCE IN KILOHMS - Concluded

Subject	Position of electrode	Day				
		0	1	2	3	4
14	Left	25	13	9	6	7
	Right	30	20	13	8	15
15	Left	60	18	Off	Off	Off
	Right	40	15	Off	Off	Off
16	Left	40	15	25	25	20
	Right	30	25	30	40	18
17	Left	25	14	14	13	65
	Right	25	12	7	13	35
18	Left	40	15	20	5	5
	Right	25	17	20	18	8
19	Left	200	4	11	15	8
	Right	200	9	13	Off	Off
20	Left	40	18	13	10	6
	Right	30	12	9	12	7
21	Left	15	5	6	7	5
	Right	20	8	8	15	11

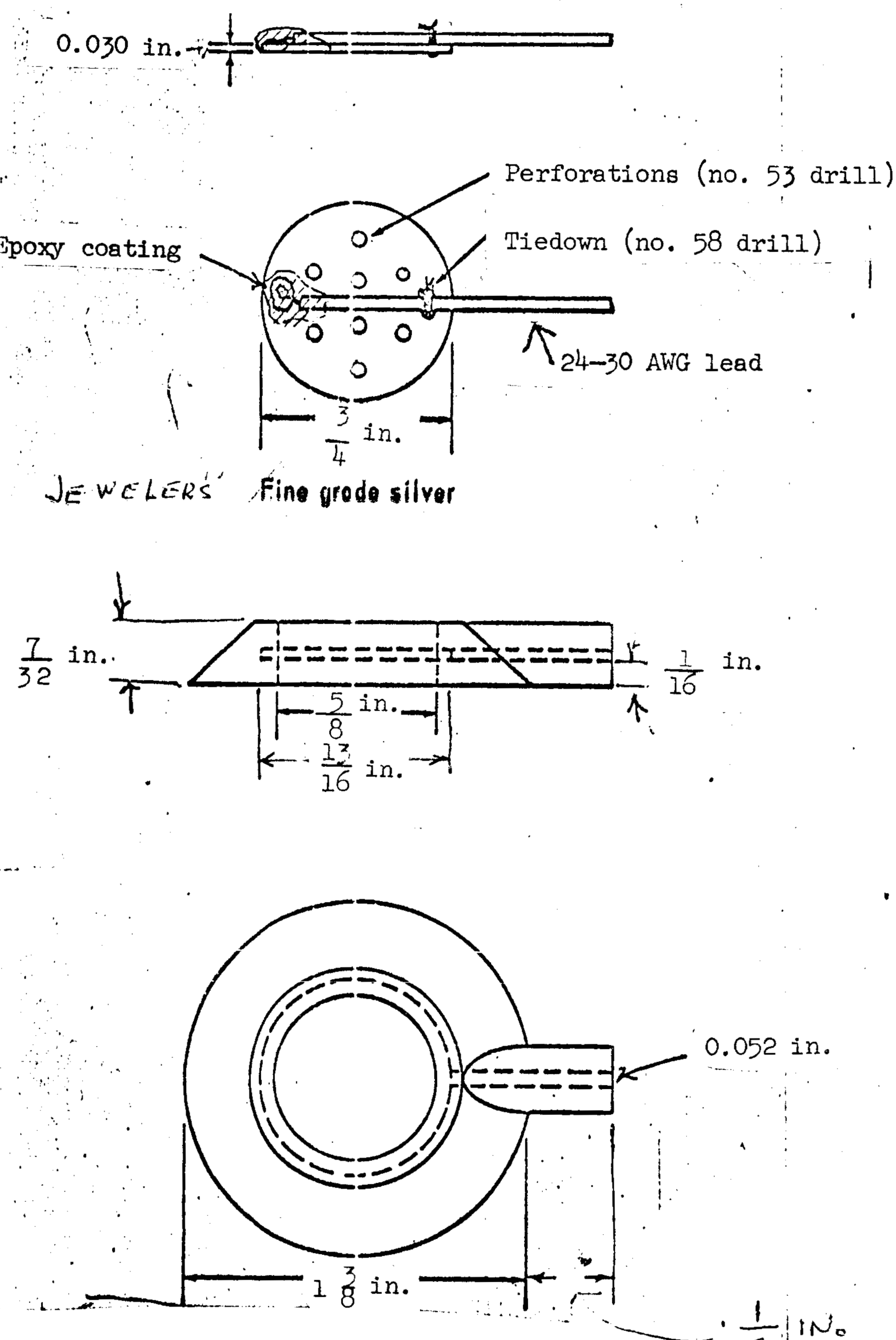

Fig. 1. Long-term electrode.

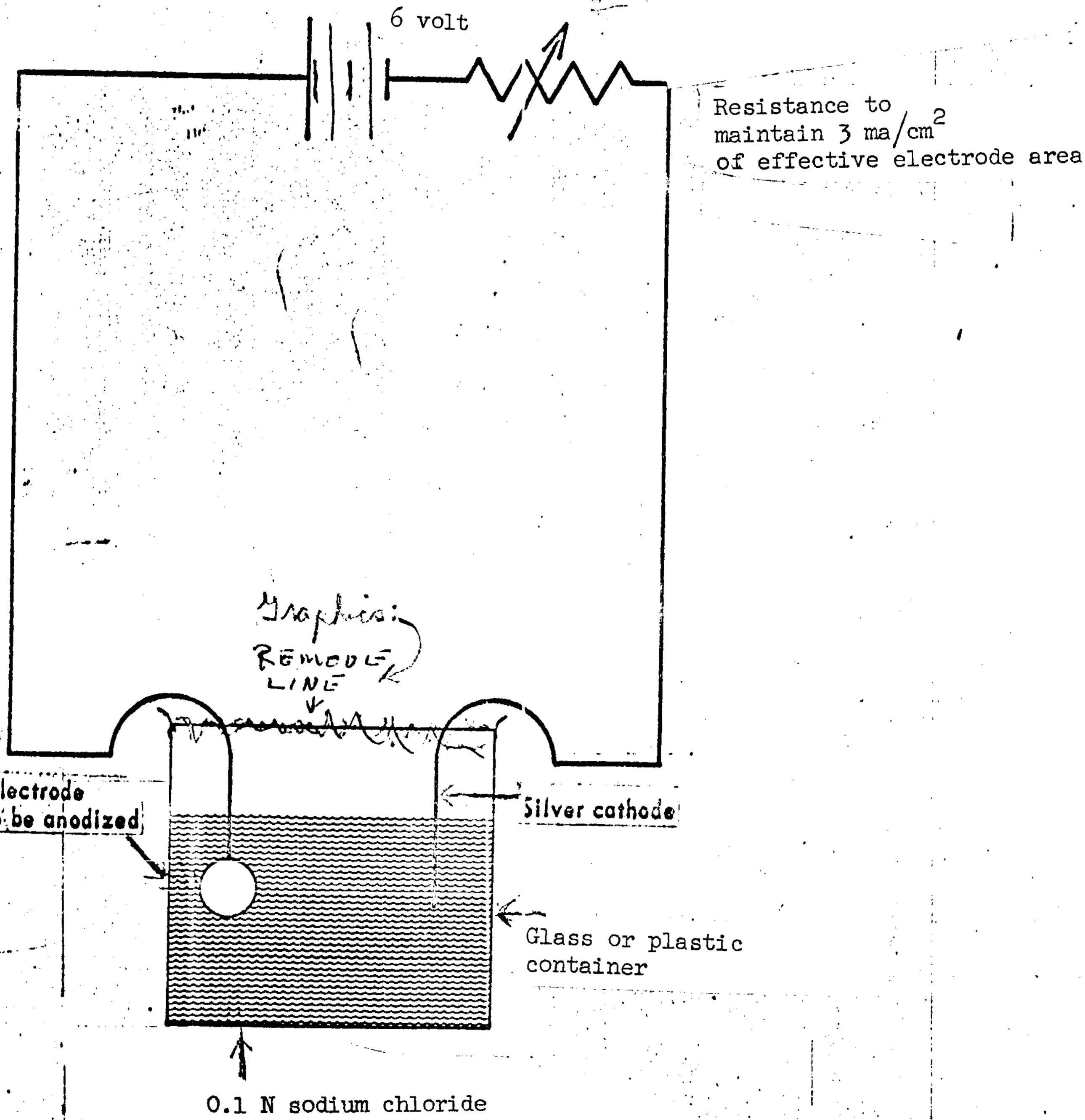

Fig. 2. Anodizing apparatus.

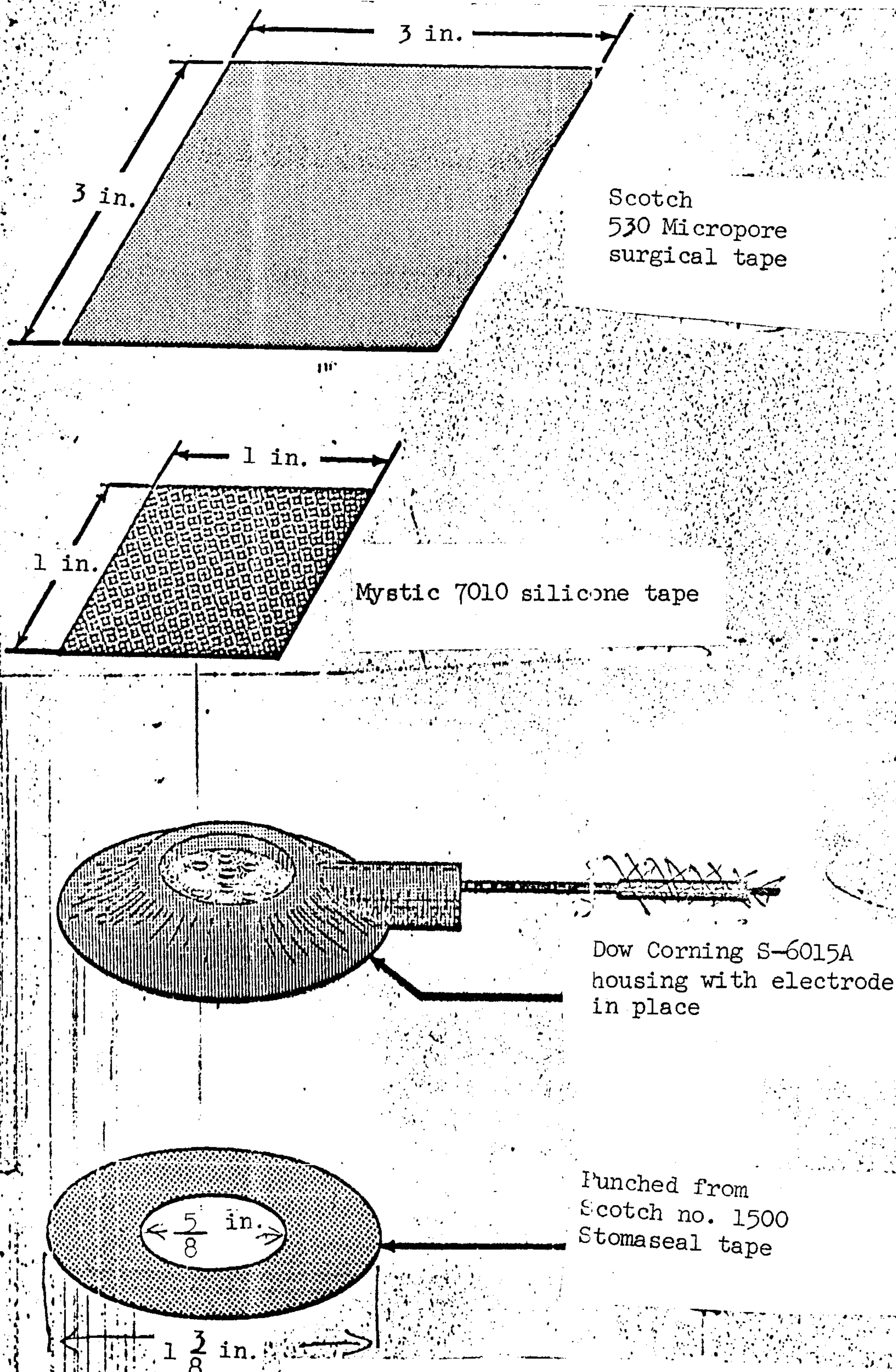

Fig. 3. Electrode assembly technique.