ELECTROCARDIOGRAPH ELECTROLYTES

BY

G. H. BELL, J. A. C. KNOX, AND A. J. SMALL

From the Departments of Physiology and of Electrical Engineering, University of Glasgow

Received April 6, 1939

The contact with the body needed for electrocardiographic purposes is often made by wrapping a few layers of gauze soaked in saline round the limb and binding over that a metal electrode. This method has the disadvantages that the limb to limb resistance is rather high and increases considerably as the gauze dries. Also the bedclothes must be protected from becoming wet when an electrocardiogram has to be taken from a bedridden patient.

If the limb to limb resistance is high the string of the Einthoven galvanometer must be slackened to increase the sensitivity, and so the record may be distorted by the alteration of the damping and the reduction of the natural frequency of the string (Pardee, 1917). In the case of valve electrocardiographs, with their high input resistance—usually about 100 times that of the string—high body resistance is not so disadvantageous ; but if it can be kept low there is less likelihood of electrical interference, and in addition the stability of the amplifier is increased.

We were led to consider these points recently while carrying out some cardiac tolerance tests by a method described previously (Bell and Knox, 1938). As some of our experiments lasted more than an hour the drying of the saline pads was a great handicap. We therefore tried soft green soap, as used by Boas (1928) under similar circumstances, and found that it fitted our requirements admirably.

Although skin resistance has often been investigated in connection with chronaxie and the psychogalvanic reflex, we could find no report of a systematic investigation into the properties of electrolytes, apart from the work of Hartridge (1931) which dealt with the effect of grease-removing substances. It was thought, therefore, that it would be interesting to compare soft green soap with certain other electrolytes.

METHOD

The electrolytes investigated were :

1. One per cent. sodium chloride in tap-water.
2. Soft green soap (*Sapo Mollis Viridis*, B.P.) which consists chiefly of an almost neutral mixture of potassium oleate with a little glycerine.

3. Cambridge electrode jelly, which is sold by the Cambridge Instrument Co. ; the composition of this substance is not issued.

4. A paste described by Jenks and Graybiel (1935), which we shall call for convenience Boston paste ; it consists mainly of sodium chloride, glycerine, water, and powdered pumice.

In the case of the first electrolyte, two layers of gauze bandage soaked in saline were wrapped round the forearms. Plymet electrodes each 14 cm. by 5 cm. were laid on the volar surfaces and held in place by rubber bands. Plymet is a soft sheet metal (supplied by Schall and Son, New Cavendish St., London, W.1), consisting mainly of lead, which is readily moulded to the shape of the arm.

In the case of Cambridge jelly a piece of the jelly about the size of the finger-nail was rubbed into the forearms for about ten seconds, as recommended by Russell (1935). The Plymet electrodes were then smeared with the jelly, put directly on the skin, and held in place with bandages and rubber bands. The soft green soap and Boston paste were applied in a similar manner.

As is well known, there are some quick changes (rise and fall of R wave) and some slow changes (T wave) in the electrocardiogram. Hence an adequate description of the behaviour of an electrolyte should include both the D.C. resistance and the A.C. impedance.

The measurements were made by means of a bridge in which the subject formed one arm, and a variable resistance with a variable capacitance in parallel formed the second arm ; the ratio arms were formed by two equal resistances of 1000 ohms. Alternating current was supplied to the bridge by a valve oscillator which gave about 8 volts at 300 cycles per second (c.p.s.). A sensitive vibration galvanometer tuned to 300 c.p.s. was used to find the balance condition. The values of resistance and capacitance in the second arm, combined vectorially, gave the A.C. impedance, Z .

Thus
$$Z = \frac{r}{\sqrt{1 + \omega^2 C^2 r^2}}, \text{ where } \omega = 2\pi f.$$

When the A.C. measurement had been made, an 8-volt battery was substituted for the oscillator and a moving coil galvanometer for the vibration galvanometer and the bridge brought once more to balance by varying the resistance in the second arm. This gave the direct current resistance, R .

RESULTS

The wide scatter of the results, which are collected together in Fig. 1, is not altogether surprising in an experiment of this nature. As it was not, of course, possible to get simultaneous values for the different electrolytes, they were applied in turn, varying the order with each subject.

The values of Z were distributed over a considerable range. One per cent. sodium chloride gave, on the whole, the lowest values (average 652 ohms), Boston paste gave slightly higher values (average 689 ohms), whilst green soap and Cambridge jelly both gave still higher values (average 768 and 754 ohms respectively).

FIG. 1.—Chart of all the observations of body resistance from forearm to forearm for the three subjects with the four different electrolytes.

R was found to be highest with 1 per cent. sodium chloride, the average value being 3080 ohms. Cambridge jelly and green soap gave the somewhat lower average values of 2010 and 2040 ohms respectively. Boston paste gave the lowest average resistance of 1100 ohms.

In order to allow of further discrimination between the solid electrolytes, variation of R and Z with time was investigated. The electrodes were left in position for varying times up to one and three quarter hours and Z and R, in that order, were measured at quarter-hour intervals. The leads were removed from the bridge between readings. In all cases Z and R rose steadily, but not very greatly, for about three quarters of an hour after application of the electrodes, when the values became nearly constant (see Fig. 2).

DISCUSSION

From the wide scatter of the results shown in Fig. 1 it will be seen that it is not at all easy to choose the best electrolyte on the basis of Z and R values only.

FIG. 2.—Variation of resistance (forearm to forearm) with time. Cambridge jelly and Green soap, subject G. H. B., Boston paste, subject A. J. S.

The best is probably Boston paste. Green soap and Cambridge jelly are only slightly inferior ; sodium chloride, on account of its very high R, is the poorest.

Drying up of the solid electrolytes does not occur to any great extent because none of them show any great increase in resistance up to one hour or more after application. There was no difference between electrocardiograms taken by means of a string galvanometer using first green soap and then Cambridge jelly. The choice between the three solid electrolytes will, therefore, have to be made on other grounds.

As green soap is a standard British Pharmacopœial substance and costs only about one penny per oz., it is to be preferred to the complicated Boston paste or the expensive Cambridge jelly.

THE EFFECT OF ABRASIVES

Boston paste is made up with a considerable proportion of powdered pumice, which at first we regarded merely as an inert base required to form the paste. But examination of Cambridge jelly points to a different conclusion. It appears to consist chiefly of sodium chloride in a base which is probably not lanoline or petroleum jelly, but which may be a gum. The jelly feels gritty to

the touch, and on dissolving away the base in hydrochloric acid an insoluble residue remains, which under the microscope proves to consist of extremely jagged particles of crushed quartz.

It is now clear why the jelly should be rubbed into the skin ; the sharp particles remove the surface cells and so contact is made with a deeper layer. Richter (1926, *a* and *b*) showed that a minute puncture of the skin below electrodes one inch square reduced *R* from 540,000 ohms to 15,000 ohms. Lewis and Zotterman (1927) came to the conclusion that the high resistance displayed by skin to galvanic currents resided in the superficial and horny layer. Accordingly it was decided to investigate the effects of abrasion quantitatively.

METHOD AND RESULTS

To one sample of green soap we added pumice in the proportion occurring in Boston paste and to another sample crushed quartz recovered from Cambridge jelly.

In these experiments the average value with green soap alone for *Z* was 885 ohms and for *R* was 2450 ohms. After rubbing in green soap with quartz the average values were *Z* 665 ohms and *R* 890 ohms, a decrease of 25 per cent. in *Z* and 64 per cent. in *R*. Rubbing in green soap with pumice left *Z* unchanged but reduced *R* by 57 per cent. Green soap covers the quartz and pumice particles and interferes with their abrasive qualities. It occurred to us, therefore, that it would be more effective to abrade the dry skin and then apply the electrolyte and electrode. The surface of the skin was rubbed gently two or three times with fine glass paper (No. 1). This raised the surface layer of cells so that the skin lost its sheen and became white in colour. This procedure resulted in a reduction of *Z* by 60 per cent. and of *R* by 80 per cent. on the average, the mean values after such abrasion being : *Z*, 400 ohms, and *R*, 500 ohms, approximately. These are the lowest values which we have observed during the whole course of this investigation.

In addition to the alteration of *Z* and *R* brought about by abrasion, it was noted in measuring *Z* that the resistive component required for balance fell to about one-half, or less, of the value before abrasion. The capacitance in parallel, however, fell to about one-tenth. For example, in one experiment before abrasion the bridge was balanced by 1790 ohms in parallel with 0.386 mfd., i.e. $Z=1090$ ohms ; after abrasion, balance was given by 368 ohms in parallel with 0.035 mfd., i.e. $Z=368$ ohms.

DISCUSSION

From the above results there is no doubt that if the lowest possible body resistance is required, gentle abrasion of the dry skin with glass paper, followed

by application of green soap and then of the electrodes is the most convenient method. Provided the rubbing is gentle and only two or three strokes are used, the skin will return to its normal appearance in a few hours. In our experience there is nothing objectionable in making this a routine procedure, provided that no irritating antiseptics, such as iodine, are applied afterwards. Only one minor difficulty appeared; it is rather hard to use glass paper on hairy parts, because the hairs roll round under the paper and no abrasion of the skin is made. This could be overcome by removing the hairs before abrasion. It was found that more vigorous glass papering, or scratching, which left a mark taking over a week to disappear, did not give lower values than the more gentle method.

By the use of the procedure recommended above the external resistance (i.e. of the patient) becomes a much smaller fraction of the resistance of the galvanometer, which should then be expected to give a better record of the potentials occurring in the patient's body. Also, when the patient's resistance is low the electrocardiograms obtained should be more standard, as even relatively large alterations of this resistance will then have little effect on the total resistance of the circuit. We have found that in the case of the A.C. bridge the capacitance value (without abrasion) varies from 0.15 to 0.5 mfd., using the same electrodes. It is difficult to predict what would be the effect of this capacitance on the electrocardiogram. The effect on damping of capacitances across the string has been studied by Gildemeister (1922). Here again, however, more standard results would be expected when the capacitance is low, as is the case when the skin is abraded, because the variations in the capacitance then become of small importance. It was also noted that when the skin was abraded the values of R and Z tended to be very steady, whereas without abrasion there was a tendency to drift.

It is interesting to speculate how far the differences which are occasionally found between records taken by string and valve electrocardiographs are dependent on high patient resistance and impedance. There seems to be a tendency to regard records taken by a string galvanometer as standard, in spite of its relatively low resistance. This tendency seems to be based more on tradition than on pure reason. It would be interesting to compare string and valve electrocardiograms in a series of cases taken with the technique described here. We venture to think that with the low patient resistances so obtained a number of the discrepancies would disappear. This question has already had some attention directed to it by Pardee (1929).

Variations in the Quality of the Green Soap.—During the course of these experiments we had occasion to purchase three separate samples of Sapo Mollis B.P. The first sample was soft, bright green in colour, and spread very easily and evenly over the skin surface. The second sample was harder, dark green in colour, very tenacious, and became caked when rubbed on the skin, refusing to spread evenly. The following figures show that this second sample was inferior to the first for our purposes. The values for R were usually over 10,000 ohms, and the average value for Z (11 observations) was 915 ohms, compared with the averages R 2040 ohms and Z 768 ohms for the first sample.

The third sample of Sapo Mollis was comparable in every way with the first, and in obtaining it the following criteria were observed. The green soap must be *fresh* and should be *bright* green in colour, and it should spread as easily on the skin as a good ointment base. It should be kept in an air-tight tin or waxed carton.

The difference in effectiveness was not due to a change in the resistance of the soap. The specific resistance of the second sample (tough soap) was 18.4 ohms per cm. cube; the value for the third sample (good soap) was 23.9 ohms per cm. cube. It is to be presumed that the lowering of skin resistance with the good soap is due to the fact that it spreads so easily and evenly over the skin.

SUMMARY

Reasons are given for the necessity of having a low limb to limb resistance when obtaining electrocardiograms either by the string galvanometer or by a valve electrocardiograph.

A comparison has been made between four electrolytes, viz. 1 per cent. sodium chloride, soft green soap, Cambridge electrode jelly, and Boston paste (Jenks and Graybiel, 1935).

The arm to arm D.C. resistances (R) and impedances at 300 cycles per second (Z) vary over a wide range for all these electrolytes. From this point of view the best is probably Boston paste, but Cambridge jelly and soft green soap are very little inferior.

Because it is cheap, clean, simple, and a standard pharmacopœial product soft green soap appears to be the most satisfactory. It should be fresh, bright green in colour, and should spread easily over the skin.

Both the Boston paste and the Cambridge jelly contain abrasives. Incorporation of an abrasive in the green soap reduced the average values of resistance and impedance to a moderate extent.

The lowest values of limb to limb resistance (R, 500 ohms; Z, 400 ohms) were obtained when the abrasion preceded the application of the electrolyte as follows: the dry skin was stroked gently two or three times with fine glass-paper, green soap was then applied and the electrodes were bound on.

We should like to thank Dr. Joseph Knox and Dr. G. W. Tyrrell for advice on certain chemical matters, and Dr. R. G. Lendrum for taking string galvanometer records.

REFERENCES

- Bell, G. H., and Knox, J. A. C. (1938). *J. Physiol.*, **93**, 36P.
Boas, E. P. (1928). *Arch. intern. Med.*, **41**, 403.
Gildemeister, M. (1922). *Pflügers Arch.*, **195**, 123.
Hartridge, H. (1931). *Brit. J. Radiol.*, **4**, 652.

- Jenks, J. L., and Graybiel, A. (1935). *Amer. Heart J.*, **10**, 693.
 Lewis, T., and Zotterman, Y. (1927). *J. Physiol.*, **62**, 280.
 Pardee, H. E. B. (1917). *Arch. intern. Med.*, **20**, 161.
 — (1929). *Amer. Heart J.*, **5**, 191.
 Richter, C. P. (1926a). *Proc. Nat. Acad. Sci., Wash.*, **12**, 214.
 — (1926b). *J. Amer. med. Ass.*, **87**, 1300.
 Russell, H. B. (1935). *Lancet*, **2**, 1172.