A METHOD OF PICKING UP CARDIAC POTENTIALS FROM MOVING HUMAN SUBJECTS FOR RADIOTELEMETRY

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Several surveys [5, 7] have shown that radiotelemetry has been increasingly used in recent years. In some cases, powerful apparatus is used operating over large distances, as in aviation and cosmic medicine, and on other occasions the observations are made at a small distance, but the subject is freely moving and is carrying out some normal activity (as in studies of the physiology of labor, sport, etc.). For this kind of work, which we may refer to as dynamic, it is important that the apparatus should not be affected by vigorous movements, and that the apparatus which is carried by the subject should be portable (it is not merely placed beside him, as it is for studies of pilots), and it must not interfere with his movements.

Considerable difficulties in recording potentials are encountered under these conditions. On the one hand, the slightest movements of the electrodes produces gross distortions of the trace, by changing the contact between the electrodes and the skin, and on the other hand, pick-up of the alternating current voltage and the varying earthing conditions give rise to maximum electrical interference [8]. The contact resistance between the electrodes and the human body is of great importance; if it is high, the interference from the mains is greatly increased. L. A. Vodolazskii[1, 2] proposed to record potentials from subjects occupied in industrial tasks by an elaborate treatment of the skin which effectively reduced the interelectrode resistance (down to 10-15 kohm, when measured at a constant current of 10 μa). In this method, the uppermost layer of the epidermis is carefully removed (by means of a paste containing finely ground pumice), and the skin was freed from grease by ether.

EXPERIMENTAL METHOD AND RESULTS

To record the pulse frequency in athletes by means of a radiopulsophone [6], the cardiac rythm was recorded from the R wave of the electrocardiogram. At the outset, we found it essential to eliminate interference caused by movements of the subject.

We first established a reliable mechanical contact by means of a special electrode (see Figure), and we used a double attachment, the electrode being fixed both by an adhesive and by suction; also, to make the contact, instead of an electrode paste we used a homogenous medium consisting of a fluid electrolyte, thus ensuring maximum constancy of the contact resistance. The electrodes consisted of tin plates and a 15 % solution of stannous chloride; it is thought [4] that this arrangement reduces to a minimum the galvanic and polarizing emf's. We have previously described in detail the rationale of this method of picking up potentials, which practically eliminates interfering voltages due to movement of the electrodes[6].

However, in many cases, and particularly when making studies indoors, electrical interference frequently occurs. If connecting the electrodes to the input of the electrocardiograph caused considerable uncompensated pickup, then there was also considerable interference, consisting of "extra" impulses to the athlete's movements; the same effect occurred when the apparatus or the supply batteries were shaken. We noted the electrostatic factors which have been described previously: in a dry building, where the humidity of the air was low, the interference increased considerable, but it was reduced if the floor was moistened; on such days, contact between the shoes and the floor gave rise to considerable interference, which could be removed by taking off the shoes. The same kind of interference was observed when our apparatus was open circuited (though of course quantitatively the effect was very different); short circuiting the input eliminated the effect entirely. All these facts convinced us that the contact resistance between the electrodes and the body should not only be constant, but should also be as small as possible.

We found that some reductions of the interference could be obtained by putting a resistance of the order of 10 - 15 kohm in parallel with the body. However, the interference remained, and the main task was therefore to improve the contacts.

We measured the value of the interelectrode resistance (IER) with the electrodes in position, and after the skin had been prepared in various ways; a number of different electrolytes and pastes and types of electrodes were used (in all 450 combinations were examined). The IER was measured by means of an ammeter and a voltmeter and an alternating potential (frequencies of 20, 100, 1,000 and 10,000 cycles, and the currents of 0.1, 0.2 and 1 ma); also direct currents of 10 and 50 μa were used as well as an ohmeter. We found that the IER depends on three principal factors — the treatment of the skin, the area of the electrodes, and the nature of the electrolyte. There was also an effect due to the surrounding temperature [3] and other factors, but they were less important.

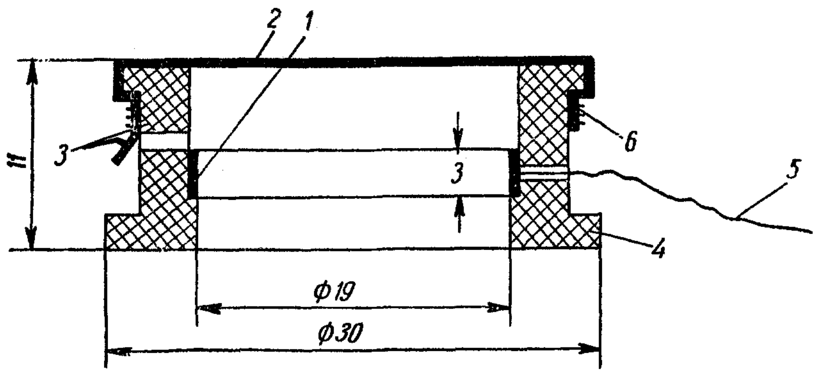

Diagram of the arrangement of the fluid suction-electrode. 1) Disc of sheet tin; 2) rubber membrane; 3) release valve; 4) ebonite electrode holder; 5) lead from electrode; 6) turns of capron thread reinforcing the membrane (the electrode is approximately two-thirds filled with electrolyte, and is attached to the skin by Kleol, so that the release valve is directed upwards. The electrode is also caused to stick on by suction by pressing on the rubber membrane; the air and part of the electrolyte then pass out through the valve.

Treatment of the Skin

The high electrical resistance of the skin is due to the properties of the cornified layer of the epidermis, and to the layer of grease. We found that when the skin is not treated, the IER is 30-45 kohm (here and later unless it is stated otherwise, the results given were obtained with 20-cycle alternating current, a current of 0.2 ma, and with the suction electrode filled with 10 % NaCl); degreasing with alcohol or with Nikiforov's mixture (alcohol and ether 1:1) reduces the IER to 10 - 35 kohm (on the chest it is lower than on the forearm), while the full treatment by Vodolazskii's method reduces it to 0.5 - 1.5 kohm. It is interesting that in the latter case, the residual IER is not due to the resistance of the whole mass of tissue between the electrodes, but mainly to the contact resistance. We have shown this to be so several times, by an experiment in which three successive measurements of the IER were made after the full treatment: 1) on the forearm, when the distance between the electrodes was 5 cm; 2) when one electrode was placed at the corresponding position on the other arm (i.e. the distance between the electrodes had increased some 10 times); 3) when the second electrode was fixed within 5 cm of the first. As a rule, the measured resistance was the same in all cases.

We showed, that with the usual methods of treating the skin, that through moistening and maceration of the epidermis there is a gradual reduction of the IER when the electrodes are left on the body for several hours; during the first 1½ hours, the IER falls about one-third of its initial value. After the full treatment, the IER is immediately lowered, and shows little subsequent change. We also confirmed that the reduction in the IER attained by the complete treatment eliminates the dependence of the resistance on the strength of the current passed. Thus, in experiment 61, when the skin was not treated, at an alternating current frequency of 20 cycles, the IER for a current strength of 1 ma was 13.5 kohm, and 0.2 ma it was 32.5 kohm, and for a direct current of 10 μa it was 68 kohm, and after the complete treatment the corresponding figures were 0.7, 0.7, and 2.4 kohm.

Area of the Electrode

The influence on the IER of the area of contact is due to the fact that the cross section of the portions of the body to which the electrodes are attached are sufficiently large in comparison with the surface of the electrodes.

Our experiments showed that lead electrode handles moistened with salt solution and clamped at the wrists, or flat lead electrodes measuring 5 x 13 cm similarly moistened gave a resistance of 4-5 kohm before the skin had been treated, and after degreasing the resistance was 2 - 2.5 kohm. It should be noted that the annular aluminium suction electrode having an area of 1.9 cm^2, and a contact area of the electrolyte with the skin (the true contact area) of about 2.85 cm^2 gave under the same conditions an IER of 30 - 45 and 10 - 35 kohm respectively.

The significance of electrode area was made very clear in experiments with needle electrodes consisting of hypodermic needles inserted under the skin. Here the IER was 1.2 - 1.7 kohm, i.e. 10 - 30% greater than that of the suction electrodes after complete treatment of the skin. The transfer of one of the electrodes on the other arm did not change the IER from the value that had been obtained when the separation had been 5 cm. It follows therefore that most of the resistances contributed at the area of contact, not through any property of the skin (because this insulating layer was excluded), were due to the very small area of contact. Because with the needle electrodes the area of contact is always small, the method has no advantage over the use of surface electrodes and complete skin treatment. This is an extremely important fact, because subcutaneous needle electrodes are usually thought to be the best method of leading off potentials [10 and others]. It should also be noted that when the electrode area is extremely small, polarization caused by the current used for the measurement becomes so great that there is no meaning in the value obtained with a direct current. Thus, the values of the IER measured with an alternating current were almost identical (of the order of 1 - 1.5 kohm), suction electrodes gave a resistance of 2.5 -5 kohm for a direct current strength of 10μa, whereas the needle electrodes indicated 100 - 110 kohm.

Properties of the Electrolyte

Initially we used a 15 % solution of $SnCl_2$, but in some people this irritated the skin, and also stained the clothing; we therefore replaced it with a solution of sodium chloride.

First of all we measured the resistance of solutions of different electrolytes. It was found that even with needle electrodes immersed in a bath containing an electrolyte, and separated by 7 mm from each other, the resistance to a 20-cycle alternating current of 1 ma varied from 10 to 200 ohm. In a 15% solution of $SnCl_2$, the conductivity was better than it was with weaker solutions, and better also than when 0.9 and 10% sodium chloride solutions were used. Tap water has a resistance about 10 times greater – 2.5- 5 kohm. Having found how low is the resistance of the electrolytes themselves, we saw that for these small values, the differences betwen them were unimportant, and we therefore changed over to using sodium chloride. There was then naturally the danger of polarization of the tin electrodes, but because there was no constant emf applied to the electrodes, the difficulty did not arise in practice.

When we compared the IER for 0.9 and for 10% sodium chloride solutions, we found that despite the small value and the near identity of the resistance of these electrolytes, after complete treatment of the skin, the 10% solution gave a much smaller IER (0.5-1.5 kohm as against 2-4 kohm). The reason was not clear; because however the IER was smaller with the 10% solution, we used this strength, and a further reason was that in tests with pastes (VNII MIiO, Al'var) the IER was no less. The 10% NaCl solution had no irritant effect, despite the fact that the complete treatment involved removal of the upper layer of the epidermis.

As a result of all our investigations, we finally settled on the following method of leading off the potentials.

We carried out a complete treatment of the skin, rubbing it with a 3 - 4 :1 mixture of a cleansing cream and pumice until a moderate degree of hyperemia had developed, and then degreasing with Nikiforov's mixture. The cleansing cream by itself degreased the skin sufficiently, because there was no further reduction in the IER after treatment with alcohol and ether; however, this latter treatment cleanses the skin, and facilitates the adhesion of the electrodes, and makes it possible to remove traces of cleol after the experiment, and we employed it for this reason. Unlike many other authors, as a conducting medium we used not a paste, but a liquid electrolyte consisting of a 10% solution of sodium chloride; its advantages were as follows: it was simple to use, easily available, and completely homogeneous; the contact resistance was therefore reliably reproduced, and it was convenient to use in connection with the suction electrodes.

To secure the electrodes to the skin of the thorax over the axis of the heart, we used a combined method consisting of adhesion with cleol, and suction. It is then not necessary to use any bandaging with plaster, as other authors have done. Further, if such electrodes are used with the subject relatively at rest, the adhesive need not be used[12].

As we have already said, the resistance to a 0.2 ma 20 cycle current was 0.5 - 1.5 kohm, and to a 10 μa direct current it was 2.5 - 5 kohm (as against 10 - 15 kohm in L. A. Vodolazskii's method, owing to the greater area of our electrodes).

This method of reducing the IER, which gives better results even than needle electrodes, should be useful for work with biological transistor amplifiers [7, 9, 10], where the low value of the input resistance demands a minimal IER.

In practice, to control the value of the IER at the beginning of any experiment, there is no need for any special ammeter or voltmeter circuit. For the area of electrodes which we used, no appreciable error in the measurement is caused by polarization when a direct current is used, and the test instrument TT-1, used as an ohmeter (on range 100) gives entirely satisfactory results. As a rule, the IER is only 10 - 30 % greater than when measured on a 0.2 ma alternating current. When the resistance is measured on the test instrument, the current passing through the body after complete skin treatment is also 0.2 - 0.3 ma. The method of leading off the potentials which we have described gives a resistance on the test meter of 1 - 2.5 kohm. This value of IER makes reliable recording of biological potentials possible, and greatly reduces interference due to bad contacts.

From our investigations we may draw the following conclusions. For radiotelemetry of cardiac potentials from active human subjects, there must be a reliable electrical contact between the electrode and the skin which will exclude unwanted voltages caused by movement of the electrodes, and which will effectively reduce the interelectrode resistance, thus eliminating a great deal of the electrical interference, and reducing amplitude and frequency distortion. We have established a method of leading off potentials which involves a complete treatment of the skin by Vodolazskii's method, and a combined method of attaching the electrodes (adhesion and suction). Instead of an electrode paste, we used a 10% NaCl solution. With this method and with the electrode construction which we developed, the interelectrode resistance to a 20 cycle alternating current was reduced to 0.5 - 1.5 kohm, while to a direct current of 10 μa the resistance was 2.5 - 5 kohm. The method is more effective than the insertion of needle electrodes subcutaneously. In addition to its application to radiotelemetry, it may also be used for other purposes to record biological potentials in moving subjects, and also for work with biological transistor amplifiers, where a low value of interelectrode resistance is essential.

SUMMARY

A comparison was made of various methods of transmitting cardiac potentials by radiotelemetry; the frequency of the heartbeat was recorded by means of the radiopulsophone, utilizing the R wave of the electrocardiogram. From the data obtained, "suction" electrodes were developed, and the paste normally employed was replaced with a 10 % sodium chloride solution. The area of electrode in contact with the skin was 2.85 cm^2. The procedure was as follows: complete treatment of the skin was applied using Vodolazskii's method: the upper epidermis was removed carefully by means of a cream containing finely ground pumice and the skin was then degreased with ether and alcohol. The electrodes were fixed with the adhesive cleol, and suction. In this way, stable contact and a low value of contact resistance was obtained, and the result was a reduction of interference originating from movement of the electrodes, and of electrical interference due to the high value of the contact resistance. When measured with a 20 cycle alternating current, the inter-electrode resistance had the low value of 500 - 1,500 ohm, a value which is actually lower than that obtained with subcutaneous needle electrodes. The method described will be of great use in work with biological transistor amplifiers.

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