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AN ERROR IN THE ELECTROCARDIOGRAM ARISING IN THE APPLICATION OF THE ELECTRODES *

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In the course of work with the electrocardiograph, there has come to my attention a phenomenon which introduces an error so large as to be of considerable importance. It is evident in Figure 1, and consists in the fact that when a constant difference of potential is applied at two points of the circuit containing the galvanometer and the patient, the resulting deflection of the string takes the form of a quick jump, as quick as the instrument can make, followed by a slow partial return toward the base line. The return takes the form of a curve such as can be seen in the figure (Fig. 1), and has a duration of from 0.1 to 0.4 second in different instances, being short when the overshoot is small, longer when it is large. When the string reaches this new level the deflection remains constant, the movements due to the heart's currents being superposed on this new base line as they were on the former one. The overshooting and slow return are usually evident to the eye of the observer in the process of standardization which is carried out before taking each lead of the electrocardiogram.

That others encounter this phenomenon is certain, for I have seen it in the records of two operators, and just recently Robinson[1] has described what must be this overshooting when he says, "Only those records have been used in which this adjustment (standardization) did not render the string sufficiently slack to cause any marked fling, which results in a definite deformity of the curves." Slacking the string is necessary when standardizing for a high resistance, but slacking the string does not lead to the appearance of "fling"; on the contrary, it causes the deflection to become slower, and to reach its maximum more gradually. A *tight* string may become periodic and go too far at first, but never when working at the sensitiveness used for electrocardiograms, unless the field strength of the magnet is very weak.

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1. Robinson, G. C.: The Relation of Changes in the Form of the Ventricular Complex of the Electrocardiogram to Functional Changes in the Heart, THE ARCHIVES INT. MED., 1916, **18**, 830.

As it is customary to standardize so that a difference of potential of 1 millivolt placed in series with the galvanometer and the patient will produce a constant deflection of 1 cm. in the base line of the record, it is readily seen that the above condition produces an error in the height of the waves of the electrocardiogram. The differences of potential producing the Q, R and S waves being of practically instantaneous production, will cause the instrument to overshoot, as it does when we apply the standard current to a degree proportional to the magnitude of the currents of the Q, R and S waves. The P and T waves, being of more gradual onset, will allow, during their development, a varying degree of the gradual return toward the base line so evident in the figure, and will accordingly not be increased proportionally to their height — will not be so high as the quicker waves — for the same strength of current within the heart. The net result then

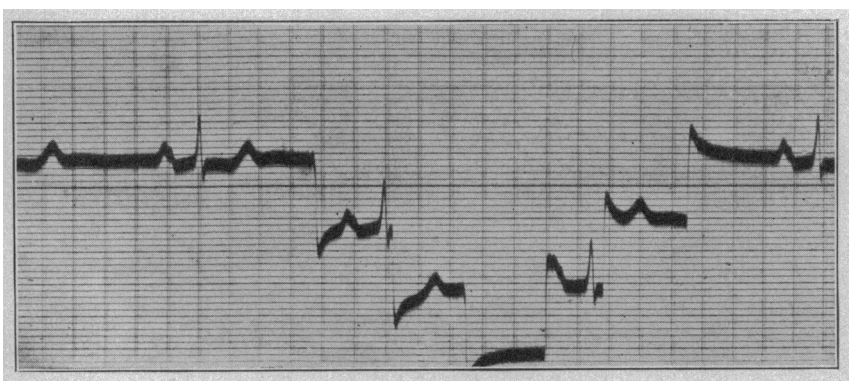

Fig. 1.—Application of successive millivolts in series with galvanometer and patient. German silver electrodes, Lead II; resistance measured as described, 5,000 ohms.

In this and all succeeding records the time interval between the corresponding line of successive pairs of ordinates is equal to 0.20 second. The distance between abscissae, 1 mm. in the originals, represents 0.1 millivolt.

All records should be read from left to right.

is a deformation of the electrocardiogram, and as this condition may be operative to a different extent in each lead, varying, as we shall see, with the apparent resistance, it will make impossible the comparison of records from the same person taken at different times, and will preclude the possibility of working out the direction of the potential within the heart which gives rise to a given wave or peak in the three leads.[2]

It was found that this effect was obtained only in cases in which

2. Einthoven, Fahr and de Waart: Ueber die Richtung u. die manifeste Grösse, etc., Arch. f. d. ges. Physiol., 1913, **150,** 275. Also Pardee, H. E. B.: Form of Electrocardiogram, Jour. Am. Med. Assn., 1914, **62,** 1311.

the resistance through the patient was relatively high, over 2,000 or 2,500 ohms. It appeared best when the resistance reached 4,000 ohms or more, being increasingly evident with higher resistance. Resistance through the patient was measured by substituting in the galvanometer circuit a resistance box instead of the patient, and determining the number of ohms which must be used in this box in order to make the deflection of the string equal to the deflection caused by the same potential

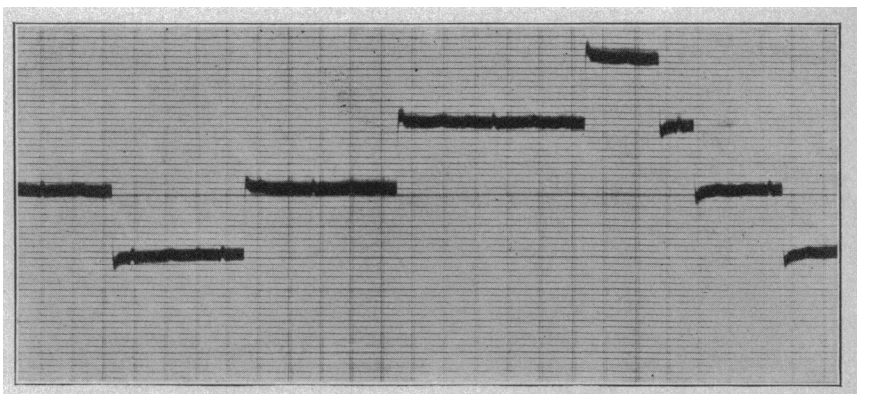

Fig. 2.—Application of successive millivolts as before, except that the lead is from the two legs, in order to minimize the electrocardiogram and make the overshooting more plainly visible; resistance 3,500 ohms.

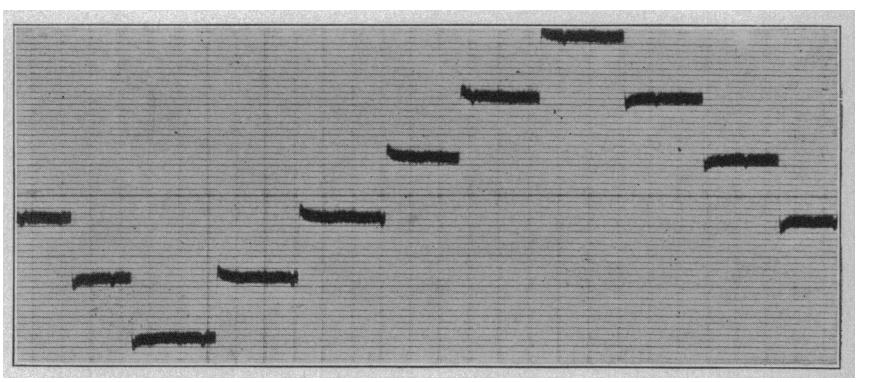

Fig. 3.—Conditions the same as in Figure 2, except that nonpolarizable electrodes were used as described in the text; resistance 3,600 ohms.

when introduced in the circuit of the patient and galvanometer; that is, 1 cm. deflection for 1 millivolt in each case. As a rule, the resistances measured by this method vary from about 500 to 1,500 ohms, usually about 1,000 ohms.

It was thought at first that this overshooting effect might be due to polarization of the electrodes, since these were not of the conventional nonpolarizable type. They consisted of a plate of German silver

about 12 by 25 cm. This was placed on the forearm or leg after the skin had been covered by a bandage soaked with strong salt solution, and the bandage was then continued over the outer surface of the metal plate. The plate was connected to the wires going to the galvanometer.[3] Polarization of the electrodes as a cause of the phenomenon was disproved by two observations: (1) The outer layer of bandages was removed from the outer surface of the metal plate and the plate was removed. The bandage being left about the extremity, its free end was immersed in a porous cup of salt solution, and this was set in a solution of zinc sulphate. The wires were attached to an amalgamated zinc plate immersed in this solution. This is a true nonpolarizable cell, and a record of the patient under these conditions showed the same resistance and the same overshooting on the application of a millivolt

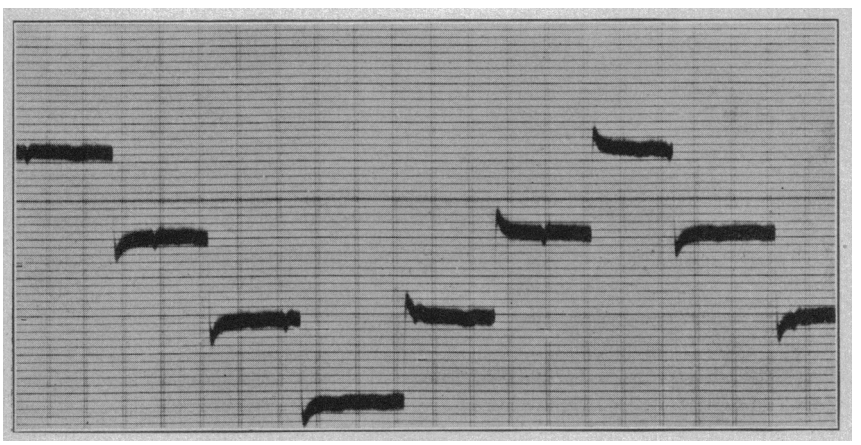

Fig. 4.—Application of millivolts as in Figure 2; resistance 4,000 ohms.

as was obtained with the German silver electrode. This is shown in Figures 2 and 3. (2) If the two metal plates were wrapped in a bandage soaked in salt solution, and were connected together by a sufficient length of bandage to make the resistance equal to that of the patient, for example, 4,000 ohms, then the application of a millivolt caused a prompt, maintained deflection with no signs of overshooting. This is identical with the curve obtained when two nonpolarizable cells are connected together by a bandage, and gives no evidence of polarization.[4]

It was further determined that this phenomenon is not due merely to the presence of a high resistance in the circuit, for if 10,000 ohms are introduced in series with the patient and galvanometer, it does

3. A full description of this electrode and of control tests will appear shortly.
4. See electrode article referred to in footnote 3.

not cause the phenomenon to appear in patients who do not otherwise show it.

What then is its explanation, and how can it be avoided? It was noticed that the phenomenon appeared chiefly or only in patients with a dry, rather bloodless type of skin, and, as has been said, only when the resistance as measured by the usual technic approached 2,000 ohms or more. It was also noticed that as the wet bandage remained longer about the extremity, the resistance as measured would gradually decrease, and with it the extent of the overshooting. Remembering that it is not the total resistance of the circuit which causes the appearance of this phenomenon, these facts lead to the conclusion that it is due to the local condition of the skin of the patient, either in the horny layer, or in the cutis as a whole.

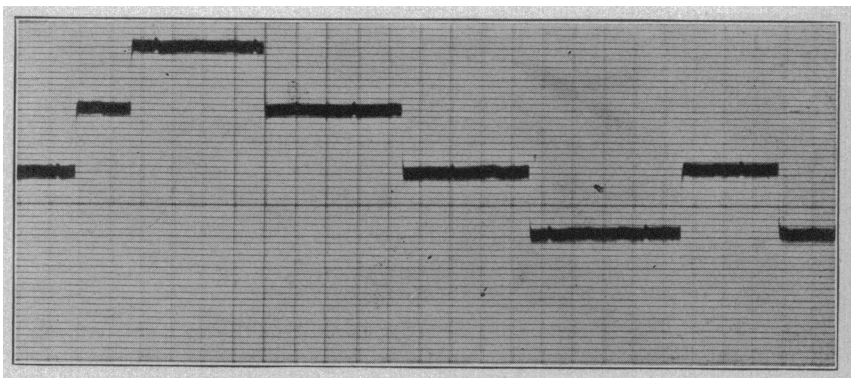

Fig. 5.—Obtained immediately after Figure 4, and with German silver electrodes, but the legs were first scrubbed with a hot salt solution and a hot bandage was applied; resistance 900 ohms.

What this condition is and how it acts to produce the effect noted, are at present undecided, though there seem to be two possibilities in each of these questions. The condition may be a dryness of the horny layer of the epidermis, or a vasoconstriction of the cutaneous vessels. The latter explanation is favored at present, because the phenomenon has been seen in several instances to pass off in such a very brief period of time, the resistance falling from 4,000 to 1,000 ohms, and the overshooting disappearing entirely in less than a minute, while in one instance the resistance rose just as suddenly from 1,200 to 4,500 ohms, and the overshooting, which had not been evident to the naked eye, became plainly so. Either of these conditions might cause the overshooting phenomenon by leading to polarization at the cutaneous surface or within its structure, but it is thought most likely that it is due to the skin functioning as a condenser surface, making the over-

shoot due to the charging of the condenser, and the slow decline due to its partial discharge through the resistance of the circuit.[5]

To avoid this source of error has been found comparatively easy, since its cause was approximated in this way, though before that time it was of common occurrence. The most important measure has been found to be the application of a hot bandage. The salt solution should be hot, preferably about 105 F., so that it stings the hand of the person applying the bandages. Of lesser importance has been found to be a thorough rubbing and wetting of the skin of the exremity before the bandage is applied. This alone will not usually suffice, but is an important accessory measure. In Figures 4 and 5 are records obtained before and after this treatment, showing the complete disappearance of the phenomenon.

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5. This investigation has been discontinued owing to its extreme technicality, and to the fact that the source of error may be avoided with the knowledge now at our disposal.