THE TELECARDIOGRAM

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THREE articles[1-3] appeared recently in the medical literature describing the successful transmission of electrocardiographic signals over standard telephone circuits. The authors point out that this provides a method whereby electrocardiograms recorded in rural areas may be interpreted without delay in large centers by persons specially trained in electrocardiography.

Without in any way detracting from the value of these communications it seems appropriate that some reference should be made to William Einthoven's original contribution to this subject. In 1905, Einthoven delivered two papers, one before the general assembly of the Société Hollandaise des Sciences and the other at a meeting of the Société de physique, de medicine et de chirurgie, which were condensed and published in 1906.[4] In this paper he gives a general description of the string galvanometer including details of the coordinates used today in measuring time and voltage and a brief account of the derivation of the standard limb leads. He then describes and names the various deflections of the normal electrocardiogram. The need for studying the electrocardiograms of patients with heart disease was recognized but to do this he had first to overcome the technical problem of obtaining electrocardiograms on inpatients when his nonportable galvanometer was situated in the physiological laboratory which stood some distance from the hospital. How he surmounted this difficulty is told in the following free translation of selected paragraphs from his paper.

19.* "It might naturally be expected that a diseased heart would trace an electrocardiogram of different form than a healthy heart. This supposition has been confirmed directly by a few preliminary observations made in my laboratory. But the number of cases so examined was of necessity quite limited in view of the difficulties involved in transporting patients, particularly when severely ill, to the physiological laboratory. However, it was imperative that the number of such observations be increased; because any extensive research into the diseases of the heart must necessarily be based upon a large number of cases.

20. It was then that Professor Bosscha suggested the idea of linking the Hospital of Leiden University by conducting wires to the Physiological Laboratory where the almost immovable galvanometer is located. This would make it possible to examine patients in the hospital with the galvanometer in the laboratory.

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21. To establish whether this idea was practical, an experiment was necessary and for this purpose Professor Place offered to devote the subsidy which La Société Hollandaise des Sciences designates for Physiological research. Mr. Place's offer was accepted and the experiment was carried out.

22. At first sight the question of the electrical connections appears quite simple. Since electric currents daily bring us information by telegraph from all parts of the world, why should not the currents originating in the heart be conducted from the hospital to the laboratory? Actually, the principle is perfectly sound, although we ran into a number of practical difficulties.

23. We availed ourselves of a circuit of the Leiden Telephone System, installed perfectly by Mr. Ribbink and Mr. Yan Bork. The wires of this system run partly underground, partly overhead. While the underground wires manufactured by the firm Felton et Guilleaume of Muhlheim-on-Rhine left nothing to be desired it was realized that the part of the circuit, running above ground, could not be used for our investigations.

24. Overhead wires are never absolutely motionless. They constantly undergo slight oscillatory movements which bring them closer together or draw them apart at irregular intervals. Thus the circuit is affected to a varying degree by the lines of force of the earth's magnetic field, creating currents which make the galvanometer unstable.

25. As it was impractical to run the entire circuit underground, we connected the terminals of the underground wires to insulated wires, twisted together so as to maintain a constant relation to each other, and surrounded them with a lead cable covering. This lead cable, heavy and flexible, could not be strung in the air so we suspended it to a steel cable. Even when this cable was blown about by the wind, there occurred no alteration of the galvanometer reading. Thus we overcame one of our original difficulties.

26. We met further difficulties involving imperfect insulation and reciprocal induction of the wires of the telephone system. Each time a subscriber receives a call, rather intensive currents are set up in the system and, if the wires are not perfectly insulated, these currents pass from one wire to the other causing the readings of the galvanometer once more to become unstable.

27. We took great pains to insulate the wires to the galvanometer as perfectly as possible. The replacement of the bare aerial terminal wires which were necessarily poorly insulated at the points of support, by the lead cables previously mentioned, constituted an important improvement. Moreover, the use of this lead cable enabled us without danger to dispense with the usual lightning arresters which are always a source of error; all that now remained to be done was to ground the lead cable. The insulation of the lead cables was always quite satisfactory but the junction of the underground and aerial wires is, even today, a weak spot. During dry weather the resistance here attains 2,000 to 3,000 megohms, but on rainy days it may fall to 10 megohms or less.

28. The mutual induction, especially troublesome in the lead-in wires when strung parallel and unprotected, has also been markedly reduced by the use of lead cables.

29. Let us now connect one end of the galvanometer string to one of the conducting wires linking the laboratory with the hospital, and ground the other end of the string. Under these conditions the galvanometer is affected by stray currents produced in the telephone system whenever a subscriber gets a call.

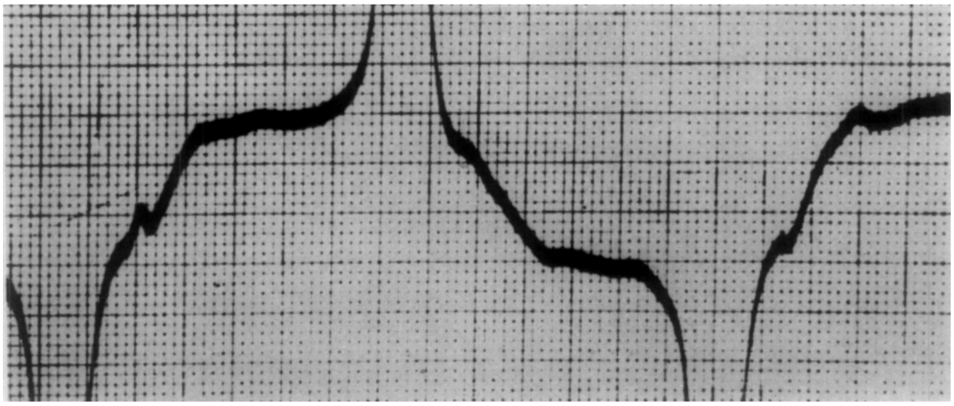

Fig. 1.—Absc. 1 mm. = 0.001 sec.; ordin. 1 mm. = 10^{-7} amp.

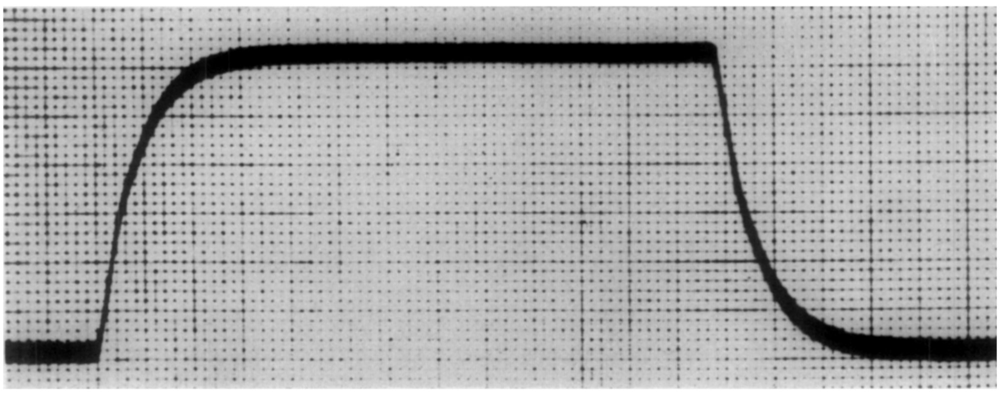

Fig. 2.—Absc. 1 mm. = 0.001 sec.; ordin. 1 mm. = 10^{-4} volts.

These stray currents are caused by imperfect insulation and by the mutual induction which still exists; they are sufficiently powerful to deflect the string picture entirely out of the field. However these currents may be reduced considerably by connecting each pole of the galvanometer to one of the wires linking the laboratory with the hospital thus eliminating the ground connection. But even under these circumstances we still observed vibrations of the string as long as the circuit was interrupted at the hospital itself or closed by a very high resistance. They ceased only when the circuit was closed at that point, either directly or by switching in a relatively weak resistance, such as that of the human body (varying from 1,000 to 2,000 ohms in our experiments). Actually, these are the exact practical conditions under which we operate.

30. In Fig. 1 (Einthoven's Fig. 12)[3] we see a photogram which was obtained by deliberately grounding one of the poles of the galvanometer string. The sensitivity of the galvanometer was about five times less than that used in taking the usual electrocardiograms. However, we note that the string picture is thrown completely out of the field by a telephone call of a subscriber. The speed of the plate movement was 1 mm. per sec., meaning that 1 mm. under the abscissa corresponds to 0.001 sec., while 1 mm. under the ordinate represents a current of 10^{-7} amp.

Fig. 3.

31. Fig. 2 (Einthoven's Fig. 13), however, represents a print obtained under the same favorable conditions as we usually maintain in recording the hospital electrocardiograms, i.e., without any ground connection and by linking the wires with the hospital by means of a resistance of 1,500 ohms. We see that there is no vibration whatever; the string remains absolutely motionless.

At a certain point in the circuit we suddenly switched in a constant potential difference of 3 millivolts. This was answered by the string with a deflection of 30 mm. Consequently 1 mm. corresponds to 10^{-4} volts which is the sensitivity regularly applied in registering electrocardiograms.

32. During the tracing, the photographic plate moved at a speed of 1 mm. per sec. Therefore 1 mm. in the horizontal direction once more corresponds to 0.001 sec. We note on the tracing that the deflection ends almost completely in 10 to 12 mm., i.e., in 1 to 1.2 hundredths of a second. This duration of the deflection differs very little, at most by some ten thousandths of a second, from that obtained when the hospital wires are not used; in any case, the difference is so slight that it may be overlooked in all the following experiments. There is a question, however, as to what the duration of the deflection would be, if the distance between laboratory and hospital was greatly increased.

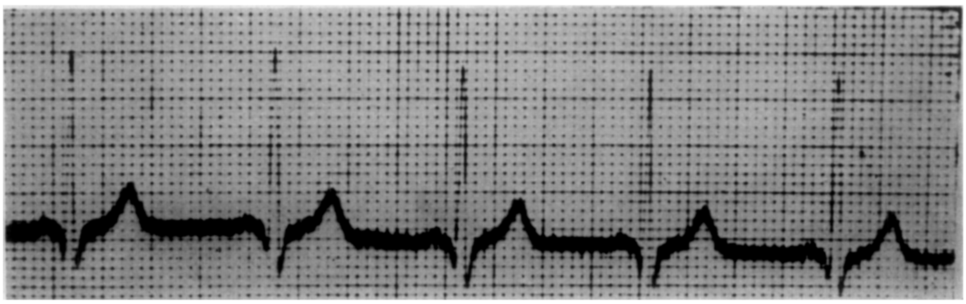

Fig. 4.—Recording from both hands.

33. As the conducting wires are lengthened their self-induction, resistance, and capacity are similarly increased, thereby setting a limit on the distance at which successful transmission can be made. The wires between the laboratory and the hospital are approximately 1 mile long. Their self-induction is negligible, while their resistance is 106 ohms and their capacity $0.075\mu f$. From this it may be calculated that wires of much greater length could be used successfully and that it would be possible to connect Leiden with The Hague or Haarlem: I believe that a practically usable connection could even be established between Leiden and Rotterdam or between Leiden and Amsterdam.

34. Let us now go over to the hospital and watch a patient having an electrocardiogram recorded. He is comfortably seated on a chair and has each hand immersed in a large jar to which is attached one of the wires connected to the laboratory [Fig. 3] (Einthoven's Fig. 14); or again he holds one hand in one of the jars and one foot in the other. The electrocardiogram, in this case actually a *telecardiogram*, is traced in the laboratory. In this way the operation is practical and simple, and it has the advantage of being quicker in comparison with the procedure used where the patient is beside the galvanometer. As a matter of fact, the operations involved in the experiment are now distributed among two groups of persons, each group having freedom of movement in its own location without interfering with the other.

35. Fig. 4 (Einthoven's Fig. 16) is a reproduction of the first telecardiogram which we registered; it is that of a healthy and vigorous man and the current came from both hands. It is completely identical to the tracing taken on the same subject in the laboratory, close to the galvanometer. The five summits, the first of which, P, is caused by the auricular systole and the four others, Q, R, S and T by the ventricular systole, are in both cases identical in form and height. With this subject, summit R is particularly high and corresponds to a potential difference of 2 millivolts".

Thus the first electrocardiogram was sent over the wires of a telephone system nearly fifty years ago, and it was by this means that the first studies of the electrocardiograms of persons with heart disease were made possible. Using the string galvanometer with its dependence upon circuits of low resistance, Einthoven recorded his "télécardiogramme" under circumstances which today are largely circumvented by the use of other methods of recording.

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