THE HUMAN ELECTROHYSTEROGRAM: WAVE FORMS AND IMPlications*

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Notwithstanding Bode's observation\(^1\) of the deflection of a galvanometric needle during a uterine contraction, the development of bioelectric studies of the uterus \textit{in situ} (electrohysterography) has proceeded slowly and sporadically. Studies both abroad\(^2, 3, 4, 6\) and in this country\(^4, 7, 8\) have made contributions. With our demonstration of a uterine electrical complex bearing a one-to-one relationship to the uterine contraction,\(^9, 10, 11\) the studies have been placed on a firmer basis. In this communication certain recent findings which indicate pacemaker function and propagated waves will be presented and their implications discussed.

MATERIALS AND METHODS

In the course of these investigations 293 subjects have been studied in labor, all under conditions of maximum comfort and quiet. Skin overlying the uterus is prepared by rubbing in ecg paste which is then washed off. Pairs of bipolar electrodes are placed on the uterus at 10-cm. spacing, or for unipolar recording the exploring electrode is over the uterus and the indifferent electrode on the thigh. Direct coupled recording systems are essential for the slow events of the uterine contraction. One-centimeter German silver electrodes and 5-mm. solder electrodes have been used. Details of the technique have been described.\(^9\)

RESULTS

For a better understanding of these studies, one of the first successful recordings of the human electrohysterogram is here reproduced (Fig. 1). Time and amplitude
calibrations are as shown, and along the lower border may be seen a signal from the patient indicating the beginning, duration, and end of her labor pain. It will be observed that this electrohysterogram consists, broadly speaking, of a diphasic wave plus a following slow event or slow wave. Lettering has been assigned arbitrarily, the letter $U$ signifying the association with the uterine contraction, with subscripts for various parts of the wave form. The subscripts are not intended to have any functional significance.

Figure 2 shows a pair of wave forms, a portion of a two-channel simultaneous recording from the left and right sides of the uterus in active labor. The upper tracing was recorded from the left side, the lower tracing from the right side. In this case, arrows indicate the beginning and end of the labor pain. The wave form from the left side may be observed to consist of an initial spikelike rise, a sharp diphasic reversal ($U_{bc}$ deflection), and finally a slow recovery. On the right side the wave form is monophasic in broad outline, beginning with the rapid $U_{bc}$ deflection and with slow recovery thereafter. High-frequency activity is marked on the right-side wave form.

**FIG. 1.—One of the earliest successful recordings of the human electrohysterogram. The wave form during contraction is diphasic. Along the lower border may be seen the signal from the subject's hand switch, indicating the beginning, duration, and end of her labor pain.**

**DISCUSSION**

With the use of a timing tape, placed so as to coincide with the onset of the $U_{bc}$ deflection of the right side, it may be seen that the comparable deflection on the left side occurs at a later time. This suggests propagated wave activity originating on the right side. This time difference, as well as the morphological differences in the wave forms, lays the basis for theoretical analysis.

1. *Prediction of the Wave Form in Non-Pacemaker Areas.*—If a model is assumed in which a single focus or pacemaker exists, with radial spread of a dipolar wave...
of excitation, as was done by Wilson and co-workers, the equation for the potential of an exploring electrode may be shown to be

\[
V_p = \frac{4c'\mu(x + a)}{\sqrt{(x + a + s)^2 + b^2}} \int_0^{\pi/2} \frac{d\phi}{\sqrt{1 - k_1^2 \sin^2 \phi}} - \frac{4c'\mu(x + a)}{\sqrt{(x - a + s)^2 + b^2}} \int_0^{\pi/2} \frac{d\phi}{\sqrt{1 - k_2^2 \sin^2 \phi}}.
\]

The equation is seen to be the resultant of the contributions of the two charged layers, as represented by the two complete elliptic integrals. The value of each integral depends upon the modulus \( k \), approaching infinity as \( k \to 1 \). This latter condition is fulfilled, in turn, as each charged layer or ring crosses under the electrode, as is possible if the potential distribution is assumed to move past a distant electrode. This equation may be plotted, and the predicted wave form in an area distant from the focus is as shown in Figure 3 (upper group, left). This wave form may be compared with the electrogram of the cardiac auricle taken at a point distant...
**Fig. 3.**—*Upper group:* Comparison of predicted and observed wave forms for regions distant from a focus: *left,* predicted waveform; *center,* observed electrohysterogram, uterine left side; *right,* observed electrogram, right auricle of heart. *Lower group:* comparison of the predicted wave form for a pacemaker area with the observed wave forms from uterus and auricle: *left,* predicted waveform; *center,* observed electrohysterogram, uterine right side; *right,* observed unipolar electrogram, sino-auricular node of heart.

a. **P**

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**focus**

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THE EXPLORING ELECTRODE (P) IS DISTANT FROM THE FOCUS. HENCE, BOTH EDGES OF THE DIPOLE WAVE (SHOWN HERE IN SIMPLIFIED FORM AS A SINGLE DIPOLE) WILL CROSS UNDER THE ELECTRODE.

PREDICTED WAVEFORM:

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b. **P**

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**focus**

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- +

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THE EXPLORING ELECTRODE IS IN OR VERY NEAR THE FOCUS. THE LEADING POSITIVE CHARGE IS INITIALLY ALREADY BEYOND THE ELECTRODE; IT WILL NOT CROSS UNDER THE EXPLORING ELECTRODE, THERE WILL NOT BE AN INITIAL SPIKE. THE TRAILING NEGATIVE CHARGE WILL CROSS UNDER, AND HENCE WILL PRODUCE A MONOPHASICALLY NEGATIVE WAVE.

PREDICTED WAVEFORM:

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**Fig. 4.**—Simplified model, in which a single dipole represents two charged layers or rings. The figure is self-explanatory.
from the SA node and also compared with the observed wave form of the left side of the uterus. It will be observed that there is good agreement between the predicted and the observed wave form. Useful ideas flow out of this agreement, as will be discussed after a consideration of the next aspect.

2. Prediction of the Wave Form in Pacemaker Areas.—If the equation as earlier described is examined for the case that the exploring electrode is in or near the focus or pacemaker, the new condition can be discussed first in terms of a more simplified model (Fig. 4). Here the leading ring of charge of the dipolar wave is represented by the single positive charge of a single dipole, and the trailing edge similarly represented by the single negative charge. Given the exploring electrode as shown, it can be observed that the leading charge is already beyond the electrode as motion begins; its contribution will be progressively decreasing. The trailing charge, however, does cross under the electrode; its contribution will rapidly increase to a maximum and thereafter trail off. A monophasic wave is thus indicated. Turning now to the derived equation, the value of the first elliptic integral will not be great, the modulus k is different from unity and will continually decrease. The second integral will have a very high value for $k \to 1$, which condition is fulfilled when the trailing charge crosses under the exploring electrode. For this case, then, the predicted wave form is monophasic, as is shown in Figure 3 (lower group, left). Here the predicted wave form for a pacemaker area (organ unspecified) is compared with an electrogram from the SA node\(^{13}\) of the heart and, in turn, with the right-side wave form of the uterus. There is interesting agreement, and on this basis arises the suggestion for the following hypothesis: (1) the human uterus in labor acts as a single-chambered auricle-like structure electrically; (2) in normal labor the uterus is under the hegemony of a single dominant pacemaker; (3) excitation would seem to spread radially, in a two-dimensional sense; and (4) present information points to a localization of the dominant pacemaker on the right side.

It is shown, last, that on the organ level it is possible to predict the wave forms of excitation in pacemaker and non-pacemaker areas. This physicomathematical approach to an interesting biological problem has good potentialities. The wave forms of the human electrohysterogram have been presented and their implications discussed.

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4 E. Lévy-Solal, P. Morin, and F. Zacouto, Presse méd., 60, 1335, 1952.