peripheral effects. This hypothesis does not explain all the observations. The other possible mechanism suggested, is a primary, direct stimulation of the adrenals by the low blood sugar, with a consequent increase in circulating adrenalin which in turn stimulates the sympathetic nervous system centers in the midbrain. Anesthesia of the sympathetic nerves prevents the transmission of these impulses to the sweat glands and perspiration does not occur. When the amount of circulating adrenalin is markedly increased then the effects are produced by peripheral stimulation of the nerve endings.

7030 C

Direction of Amoeboid Movement of Leucocytes on a Glass Surface in an Electric Field.

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It is well known that in inflammatory areas the hydrogen ion concentration is frequently increased.[1] According to Abramson,[2, 3] the chemical changes in tissues incidental to injury would give rise to differences in electric potential sufficient to account for emigration of leucocytes. Migration in such an electric field might be due in part to electrophoresis, in part to amoeboid movement of which the direction was determined by the electric field.[4]

The present report is concerned only with the latter manner of progression, amoeboid movement in an electric field, a phenomenon that has been termed, somewhat loosely, galvanotaxis. It seemed of some interest to those of us who are concerned with the general pathology of inflammation and especially with the mechanism of chemotropism to learn whether the amoeboid motion of leucocytes can in fact be directed by an electric current, and, if so, toward which pole the cells move.

Only two papers on galvanotaxis of leucocytes have been found in the literature. Mendelssohn[5] reported that the cells moved

[1] Schade, H., Neukirch, P., and Halpert, A., *Z. Exp. Med.*, 1921, **24**, 11. For brief review of literature see Loos, H. O., *Z. Exp. Med.*, 1931, **75**, 463.

[2] Abramson, H. A., *J. Exp. Med.*, 1927, **46**, 987.

[3] Abramson, H. A., *J. Gen. Physiol.*, 1928, **11**, 743.

[4] Abramson, H. A., in Alexander's Colloid Chemistry, New York, 1928, **2**, 701.

[5] Mendelssohn, M., *Comptes rend. Acad. des Sciences*, 1916, **162**, 52.

toward the cathode, Feringa,[6] that they went toward the anode.* The latter of these brief reports does not make it clear whether the author was actually observing the effect of galvanotaxis or electrophoresis. Yet the distinction is important for the present discussion. In electrophoresis the cell is passively transported by electric forces through the liquid or jelly[3] in which it is suspended. In galvanotaxis the cell is actively crawling on a solid support (a glass slide); the electric current merely determines the direction in which it crawls.

Another distinction may be drawn. In electrophoresis the mobility or bodily movement is proportional to the applied electric potential, whereas in galvanotaxis, no effect is evident for small potentials, the effect being easily observed only when the current density exceeds a minimal value.

The apparatus in the present experiments was similar to the one used by Hahnert[7] in studying amoebae. At each end of an ordinary glass slide is placed a paraffin cup containing aqueous copper sulphate solution, into which dip copper electrodes. Bridges of agar jelly (agar 2%, NaCl 0.8%) conduct the current from the paraffin cups to very thin, moist strips of filter paper. These strips pass under opposite edges of a coverslip. A drop of cell suspension (exudative rabbit polymorphonuclear leucocytes resuspended in serum) is placed between coverslip and slide and the preparation is sealed with vaseline. It is placed on the stage of a microscope in a warm box and observed with the oil immersion lens. In these experiments an E.M.F. of 45 volts was used. The field strength was not ascertained.

When a new preparation is desired, the electrode cups and agar bridges are moved onto a fresh slide, fresh strips of filter paper are put in position and a drop of cell suspension mounted between slide and coverslip. Such a preparation can be made in less than 5 minutes.

The cells are first observed with the current off. After a few minutes amoeboid motion begins and the cells wander over the slide at random. The current is then turned on, but for about 2 minutes the crawling cells continue to move at random, showing no response to the current, though cataphoresis of suspended particles begins at once. After about 2 minutes the crawling cells begin to move toward the negative pole or cathode. Observation with the oil

[6] Feringa, K. J., *Arch. néer. physiol.*, 1925-6, **10**, 406.

* Amoebae generally move toward the cathode.[7]

[7] Hahnert, W. F., *Physiol. Zool.*, 1932. **5**, 491.

immersion lens reveals no change in the character of amoeboid movement, except in its direction. The cells are not floating, but are attached to the glass slide. Protoplasmic streaming, as revealed by movements of the cell granules, is normal and does not suggest that the cell is being dragged over the glass by the electro-osmotic stream.

When the current is reversed, the cell continues to move in the same direction as before, that direction being now toward the anode. However, after a minute the cell gradually turns around until, after about 2 minutes, it has reversed its direction and is moving once more toward the cathode. This result was always obtained as long as the cells remained in good condition.

The accompanying camera lucida drawing shows the changes in direction of a representative leucocyte.

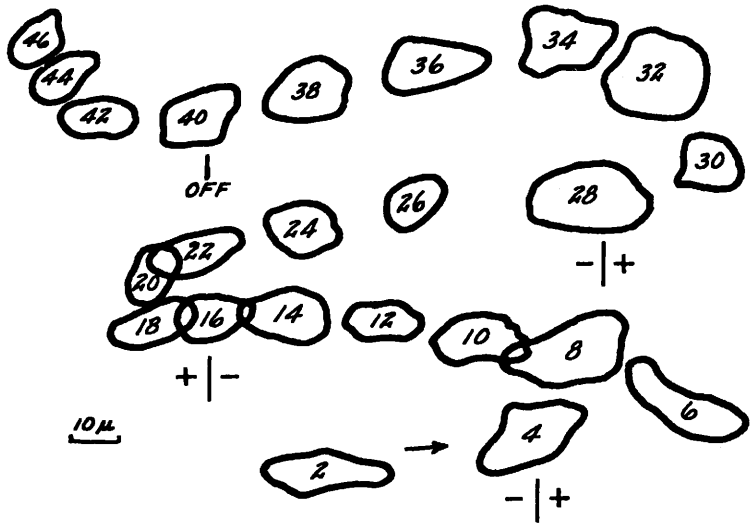

FIG. 1.

Camera lucida drawings of a single leucocyte at minute intervals. When the leucocyte was at position 4 the current was turned on, with the negative pole to the left. The cell gradually turned around and went to the negative pole. This response was repeated where the current was reversed with the cell at position 16 and again at position 28. At position 40, the current was turned off.

It is concluded that under these conditions exudative polymorphonuclear leucocytes of the rabbit, placed in an electric field, progress by amoeboid motion toward the cathode. These experiments do not allow us to decide whether the cells are responding to electric polarization (galvanotaxis), to stimulation by the electro-osmotic flow of water, or to other factors that might determine the direction of amoeboid movement.

Evidently cells in an electric field may show either of 2 types of locomotion: first, electrophoretic movement, which is easily observable at low field strength, forcing the leucocyte toward the anode[2]; second, amoeboid galvanotactic movement in higher field strengths, forcing the leucocyte in the opposite direction toward the cathode.

Whether these 2 factors are of importance in determining the direction of locomotion of leucocytes in an inflammatory area remains to be determined.

7031 C

A Thermoelectric Blood Flow Recorder in the Form of a Needle.

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The needle flow recorder described here was primarily designed to measure rate of blood flow through the internal jugular vein of man. Preliminary work on animals has shown that the device possesses certain characteristics that would seem to promise it a sphere of usefulness in a variety of problems where blood flow is an important variable. The advantages of the device are as follows: Its use entails only a minimal trauma. It can be applied to the study of flow through relatively inaccessible structures. The method makes it possible to measure qualitatively the changes in blood flow through a vascular tissue without isolating or cannulizing the afferent or efferent vessels, and thus enables one to study the blood flow through a tissue or organ, the blood supply of which is not capable of being completely isolated. It also makes possible relative determinations of the blood flow through various parts of the same organ or region. This has not been possible by any method previously described. The thermoelectric methods for measurement of volume flow of blood previously reported require cannulization of a vessel and the passing of heparinized blood through a water jacket, the temperature of which is thermoelectrically determined (Bronk and Gesell[1]); or the isolation of a vessel, the heating of the blood therein by means of a high frequency current, and the determination of the temperature gradient along the

[1] Gesell and Bronk, *Am. J. Physiol.*, 1926, **79**, 61.