THE SPECIFIC RESISTANCE OF BIOLOGICAL MATERIAL—
A COMPENDIUM OF DATA FOR THE BIOMEDICAL ENGINEER
AND PHYSIOLOGIST*†

L. A. GEDDES and L. E. BAKER

Section of Biomedical Engineering, Department of Physiology, Baylor University College of Medicine,
Houston, Texas 77025

Abstract—The paper traces the history of, and tabulates determinations of the electrical resistivity of blood, other body fluids, cardiac muscle, skeletal muscle, lung, kidney, liver, spleen, pancreas, nervous tissue, fat, bone, and other miscellaneous tissues. Where possible, the conditions of measurement are given.

1. INTRODUCTION

Ever since the discovery of bioelectric events, there has been an interest in the ability of living tissues to conduct current. Those who have measured bioelectric events arising at a distance from the electrodes have speculated on possible alterations produced by intervening tissues. Although the conducting properties of body tissues and fluids permits measurement at an appreciable distance from a bioelectric generator, the voltages measured are considerably reduced. The fact that the tissues between a bioelectric source and the recording electrodes may possess different electrical characteristics gives rise to the possibility that not only may amplitude be reduced but waveform may be altered, as exemplified by noticeable differences in waveform of the EEG when recorded on the scalp and directly on the cortex. These facts have led many investigators to measure the specific resistance of biological material at different frequencies to better evaluate and to provide some theoretical basis for determining to what extent the volume conductor matrix in which the bioelectric generators are embedded can be considered homogeneous and in what manner inhomogeneities may alter and bias the diagnostic information contained in recordings of bioelectric events. While the matter is still unresolved, there has been published a considerable amount of valuable data relative to the conducting properties of tissues. In addition to their ultimate use in resolving the problem just described, such data have immediate value to the biomedical engineer and physiologist. Not only do the data have relevance to a better understanding of the location and orientation of bioelectric generators, they have value in understanding the bases for techniques in which current is sent into the body via electrodes placed on its surface. For example, in the measurement of blood flow by the impedance method (Nyboer, 1959), currents in the microampere range are caused to flow through the head, thorax limbs, digits, ventricular cavities and other organs. Respiration is measured by changes in transthoracic impedance. The contraction of skeletal muscle, and changes in the

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fat and fluid content of tissues can be detected by impedance. A review of these techniques was presented by Geddes (1964).

Currents in the milliampere range are passed through electrodes in direct contact with living tissue to stimulate nerve, muscle and gland and to produce anesthesia (Geddes, 1965). In ventricular defibrillation and electroshock therapy, currents in the ampere range are employed. A knowledge of the resistivities of the structures between electrodes used for these purposes would assist in providing an understanding of the current paths.

Irritable tissues are often stimulated by transmission of electrical energy into a small receiver implanted within a subject. For example, in the unanesthetized animal, various parts of the nervous system have been stimulated by the use of a receiver consisting of a single or three orthogonally-mounted secondary pickup coils implanted below the integument. The terminals of the receivers were connected to electrodes affixed to nervous tissue and electrical energy was coupled into the implanted receiver from an external primary coil. In one series of investigations, the external primary was energized by line voltage. Descriptions of these methods have been presented by Loucks (1933), Fender (1936, 1937), Clark and Ward (1937) and Harris (1947). Similar studies using direct current pulses applied to the primary coil have been described by Chaffee and Light (1934), Light and Chaffee (1934), Loucks (1934) and Harris (1948). Bickford (1965) has even stimulated irritable tissues in the frog and man without the use of an implanted secondary by discharging a large condenser through a primary coil which induced eddy currents in the body tissues. The eddy currents were of sufficient intensity for stimulation of superficial nerves and muscles.

Radio frequency carriers have also been used to transmit energy into the body. Frequencies ranging from 430 kc/s to 300 Mc/s have been used to transmit stimuli to implanted receivers connected to various parts of the nervous system. Descriptions of these applications were presented by Newman (1937), Fender (1941), Greig (1944), Gengerelli (1948, 1950), Lafferty (1949), Mauro (1950), Verzeano (1953) and Riggle (1957). Using the same technique the bladder was stimulated by Bradley (1962, 1963) and Boyce (1964). Cardiac pacemakers using the same principle have been described and are now currently in use. An excellent review of these applications has been presented by Rogel and Mahler (1965).

Larger amounts of energy have been transmitted into devices within the body which in turn re-transmit energy to a receiver located outside of the body. For example, this technique was used by Farrar (1960–61) and Haynes (1960) for continuous measurement of pressure in the gastrointestinal tract surrounding a swallowed pill receiver–transmitter; the device sometimes being called a transponder.

Still higher power levels have been transmitted to energize other implanted devices. For example, Richwien and Millner (1966) used this method to maintain the power supply of a cardiac pacemaker. Furman et al. (1965) described an implanted cardiac pacemaker in which the batteries were recharged by an external radio transmitter. Schuder (1961, 1962, 1963) has investigated the problem of transmitting power levels of 50 W through the thoracic wall of a dog; the goal being to develop the capability of energizing an electric motor to activate an artificial heart.

In all of these energy transport investigations, the efficiency is often low because of the loose coupling between the transmitting and receiving coils and the losses in the intervening biological materials. Calculations of the expected efficiency and the amount of heat developed in the tissues depend upon knowledge of the electrical characteristics of the biological materials.

In view of the obvious importance of the electrical properties of tissue to a wide range of physiological studies, as shown by the foregoing examples, the authors have collected together an extensive body of data which describes one of the most important electrical parameters of biological material, its specific resistance. The data appearing in this paper were derived from