MODERN ASPECTS OF THE ELECTRICAL RESPONSES OF MUSCLE

1. The Modern Concept of Muscle Testing

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During recent years developments in electronic engineering have revolutionized the science of electrodagnosis. In particular, the scope of electromyography and electroencephalography has increased very greatly. Similar advances have been made in the technique and interpretation of electrical testing of excitable tissues which form the subject of the present consideration.

The fact that muscle and nerve tissue will respond to stimulation by an adequate electric 'shock' has been known since the discovery of electricity itself. The basic physiological facts regarding this response are well known, but even now the exact nature of the process of excitation is unproven. Muscle and nerve tissue will, in general, respond to electrical stimulation either completely or not at all ('all or none law'), and it is necessary to apply a threshold level of stimulus in order to excite a response from the tissue concerned. Clinical assessments are made upon changes in this 'threshold value' of excitation.

In clinical studies estimations are based upon excitability as a function of time, and these make it possible to distinguish between normal and denervated muscle. The early investigators using electricity as a stimulating agent observed that damaged nerve and muscle responded less readily to shocks from an induction coil (faradic stimulus) than to an applied direct current (galvanic stimulus) although this difference was almost unnoticeable in normal tissue. These observations were summed up by Erb in the classical 'reaction of degeneration' in which denervated muscle is stated to respond to a galvanic stimulus but not to a faradic shock. The loss of response to faradic stimulation does not, of course, occur until sufficient time has elapsed after the nerve injury for degeneration to occur. Thus, in a case of complete severance of a peripheral nerve, normal electrical reactions in the paralysed muscle are to be expected for a minimum of four days after the injury, and the characteristic reaction of degeneration may not appear for two weeks. In addition Erb also described the slow wave-like contraction of denervated muscle in response to direct current stimulation in contrast to the brisk contraction and quick relaxation of normal muscle and the altered threshold value of cathodal and anodal stimulation. This latter finding is now regarded as being of less significance than formerly, for whereas normally the 'cathode closing contraction' is greater than the anodal, recent work has shown that the formerly described reversal of this ratio does not occur following denervation, although the responses may become more nearly equal. Hyperirritability of denervated muscle to galvanic stimulation is a fairly constant clinical finding.

The classical galvanic-faradic test is therefore seen to be of value for distinguishing between normal and denervated muscle, but it is of little use in detecting partial denervation, such as may occur in spinal cord lesions or during the process of degeneration and regeneration of motor nerves.

Recent Methods of Electrodagnosis

The well-known method of muscle testing discussed above is a purely qualitative method, for the 'galvanic' impulse is merely an applied direct current of indefinitely long duration, and the faradic impulse is a typical induced current, whose characteristics vary with the type of coil and
technique employed, but whose physiologically
effective duration may be regarded as being
approximately one millisecond.

A number of quantitative methods of electro-
diagnosis have been described in recent years:—
1. Determination of chronaxie by means of a
condenser discharge apparatus or thermionic valve
stimulator (Watkins, 1942; Pollock et al., 1945).

2. Determination of complete intensity duration
curves (Ritchie, 1944).

3. The measurement of accommodation by
means of applied currents with slowly increasing
potential (Kugelberg, 1944; Pollock et al., 1945).

4. Determination of the galvanic tetanus ratio
(Pollock et al., 1945).

Of these methods the second is the most
practical precision technique generally applicable
in this country. The use of progressive currents
promises to be of value, but as yet no commercial
instrument for the production of this type of
current is available.

Intensity-Duration Curves

A number of forms of commercial apparatus
suitable for the determination of intensity-
duration curves are available. Apart from the
earlier instruments whose output was not ade-
quately stabilized, the thermionic valve stimu-
lators used in this work are of two types, known
respectively as 'constant current' and 'constant
voltage' instruments. These stimulators are so
designed that the measured output remains con-
stant within narrow limits independent of varying
external factors, of which the patient's resistance
is the most important.

The constant current stimulators provide a
stabilized stimulus in which the current flowing
remains constant at a set value, although the
voltage varies with the patient's resistance; in this
form of apparatus the intensity of the stimulus is
measured in milliamperes. Conversely the con-
stant voltage instrument provides a specified
stimulus, whose intensity is measured in volts, but
the current flowing is unspecified as it, again,
varies with the resistance of the patient.

Mention is made of these different forms of
stimulation, as it is most important to employ a
standardized technique, including the use of
standard electrodes and standard conditions of
testing, if direct comparison of intensity-duration
curves is to be made. It is absolutely essential to
employ the same type of apparatus, for the curves
differ considerably with the use of the two types
available (Fig. 1). The chronaxie time of normal
muscle is of the order of 0.1 to 1.0 millisecond
using a constant current instrument, and 0.01 to
0.1 millisecond with the constant voltage type.

The Clinical Interpretation of Intensity-
Duration Curves

Muscle tissue has been shown to possess two
distinct excitabilities, one having very much
slower characteristics than the other. The ex-
itability curve showing the shorter duration
characteristics has been shown to be due to the
indirect stimulation of the muscle fibres via the
intramuscular nerves, whereas that of longer dura-
tion characteristics is due to direct excitation of the
muscle fibres themselves. Normally, therefore,
the intensity-duration curve is that of the intra-
muscular nerve fibres, which are far more exci-
table than the simple muscle tissue, but in total
denervation, provided that nerve degeneration is
complete, the curve is that of muscle tissue alone
(Fig. 2). As previously stated, after a period of
two to four weeks a completely denervated
muscle becomes hyper-irritable to long duration
stimuli. An early sign of regeneration is the
cessation of this hyper-irritability, as measured by the increase in intensity of the stimulus required to produce a response, if applied for an indefinite time (the 'rheobase'). In practice, a stimulation duration of 100 milliseconds suffices to determine the rheobase.

In cases of partial denervation and during the course of regeneration, the excitability curve may be found to be discontinuous. This discontinuity represents the responses of tissues of different excitabilities, one portion being that of the intra-muscular nerves, the other that of the denervated muscle. In addition, it is possible to observe the different response of the two components in the muscle, for the response to the stimuli of long duration is the slow wave-like contraction typical of denervated muscle, the response to the shorter duration stimuli is the typical brisk reaction of normal muscle. The normal muscle component does not usually appear in response to the long duration stimuli, for the state of hyper-irritability of the denervated muscle causes it to respond to a lower threshold of stimulation. A typical curve of partial denervation is shown in Fig. 3.

Numerous other factors will influence the shape of the curve; of these, muscle ischaemia and oedema are important. Furthermore, the interrupted curve of partial denervation may be missed if insufficient readings are taken.

In conclusion, it may be stated that recent advances in technique have considerably increased the clinical value of diagnostic muscle stimulation. While the classical method served within limits to distinguish normal and denervated muscle and to support diagnoses of myasthenia and myotonia, it is now possible to give more accurate information including that of partial denervation, and the quantitative methods employed enable the progress of a condition to be accurately followed. Bauwens (1941), however, has emphasized that these advances are no more than an expression of the principles of the classical muscle test in quantitative terms, and in no way directly indicate the underlying pathological lesions. The results obtained must always be considered in conjunction with the general clinical assessment of the case under consideration.

The author wishes to thank Dr. Bauwens for his advice and permission to reproduce figures taken from the records of the Department of Physical Medicine at St. Thomas's Hospital.

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Postgrad Med J 1950 26: 222-224
doi: 10.1136/pgmj.26.294.222

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