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 electrodiagnosis. 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 Electrodiagnosis

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 adequately stabilized, the thermionic valve stimulators 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 constant 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 constant 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

Fig. 1.—Cv is an intensity-duration curve for normal muscle, using a constant voltage stimulator. Cc is a curve for the same muscle using a constant current instrument.

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 excitability 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 duration characteristics is due to direct excitation of the muscle fibres themselves. Normally, therefore, the intensity-duration curve is that of the intramuscular nerve fibres, which are far more excitable 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 three 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 intramuscular 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.

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Fig. 2.—N is an intensity-duration curve is normal muscle ; D is a curve typical of denervated muscle.

Fig. 3.—An interrupted curve typical of partial denervation.