Clinical Electromyography

Second Edition

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Foreword

The history of electrodiagnosis of paralytic disorders has been a chequered one. The 'electrical reactions' of muscles introduced by Erb (1868) were of little assistance to the clinician, since consistent results were only found in completely denervated muscle with carefully standardised technique. The differential response to galvanic and faradic stimulation of the motor point of muscle is also of little use in detecting partial denervation. Greater discrimination is obtained by plotting an intensity-duration curve using the more accurate electronic stimulators of different types (Ritchie, 1944). Although this method of electrodiagnosis suffers from the more severe practical disadvantages of the earlier methods in being inapplicable to deeply situated muscles and fatiguing to patient and investigator, as it requires detection of threshold contraction responses of muscle, it has the important advantage of being suitable for recording by a technician with limited training. Although quantification of the response by chronaximetry is now of only historical interest, the method is still capable of providing valuable information. Excitability threshold changes in a peripheral nerve may provide diagnostic and prognostic information earlier than any other method of electrodiagnosis. Professor Ritchie has made valuable contributions to the technical and practical aspects of nerve excitability measurement and in this book describes some recent advances that demonstrate its continuing value. If the intensity-duration curve is plotted with a sufficient number of points, inflections ('kinks') indicating a cross-over point from the excitability curve of one unit to another make it possible to detect partial denervation, but this requires a meticulous technique used by few physiotherapists. The fundamental disadvantage of the conventional technique is that it detects the lowest threshold nerve or muscle fibres for each stimulus. It only requires survival of some normal low threshold nerve fibres in a damaged nerve trunk, and the intensity-duration curve will remain normal. The response of higher threshold units can be determined by using an electromyographic index of motor-unit response but the essential simplicity of the method is then lost.

These limitations and the requirements of peripheral nerve surgery in wartime led to the development of clinical electromyography in the

1940s. Adrian and Bronk's use of the concentric needle electrode in 1929 and the development of differential amplifiers and the cathode-ray oscilloscope had provided the technology for investigating the function of single motor units and their summation in voluntary contractions of different degrees, and, in 1938, Denny-Brown and Pennybacker investigated the spontaneous activity of partially or completely denervated muscle. This technique was exploited by Buchthal and Clemmesen (1941) and Weddell *et al.* (1944) for the investigation of neurogenic muscular atrophy and peripheral nerve injuries.

A new dimension was introduced by Kugelberg (1947) who recognised morphological differences in the motor unit action potentials in muscular disorders. Since then, an important function of electromyography has been the differential diagnosis between neurogenic and myogenic weakness.

In the 1950s interest reverted to the study of peripheral nerve disease and spinal cord function with the introduction of measurement of motor nerve conduction velocity in neuropathies (Simpson, 1956), extended to sensory nerves by Gilliatt and Sears (1958), and the investigation of reflex activity by Magladery and McDougal (1950) and Paillard (1955). Quantitative evaluation of electromyographic data has become essential (Buchthal *et al.*, 1954). Dr Lenman has made valuable contributions on integrated electromyography.

In the present decade the introduction of digital computers for extracting small biogenic signals from 'noise', and for carrying out statistical sorting and cross-correlation procedures, is extending electrodiagnostic techniques and opening the way to detailed quantitative studies of the physiology of the motor unit in health and disease.

These advances have removed electrodiagnosis from the sphere of the medical ancillary, and of the practitioner of physical medicine to that of the clinical neurophysiologist. The time has now come when the vast amount of information must be made available to a generation of physicians and physiologists who have not grown up with it. The physician, usually a neurologist, must have knowledge of the scope and limitations of electrophysical techniques. He must realise that he should ask a physiological question and will receive a physiological answer which he must then integrate with other clinical evidence in making a diagnosis and prognosis. On the other hand, the physiologist must have sufficient training in clinical neurology to understand the nature of the problem and the probable differential diagnosis. In this book the authors have assembled selected data on electrodiagnostic methods. It is not intended to be an exhaustive treatise on clinical neurophysiology, but it provides sufficient neurophysiology for the clinician to understand the nature and scope of the techniques and sufficient clinical information for the physiologist.

The most satisfactory way to learn a technique is by instruction from a master, and equipment is far from being standardised. Nevertheless, the instruction given in this handbook should provide the necessary scientific background to enable newcomers to electromyography to learn the art for themselves.

J. A. Simpson

Preface to the Second Edition

Since the first edition of this book there have been important developments in the application of electrophysiological methods to the study of neuromuscular disease. These have been in part technical, since there have been many useful advances in technique, particularly in obtaining quantitative data, and new work has led to a better understanding of physiological mechanisms underlying disease. In addition, there has been a considerable growth of knowledge concerning some of the disorders that can be studied by electrophysiological means, and many techniques that at one time were confined to the experimental laboratory have come into routine clinical use.

In preparing a second edition the aims have been to bring the existing text up to date, make the book more comprehensive by introducing new material, and at the same time to retain the original emphasis on fundamental principles without sacrificing simplicity of presentation. While the introduction of new techniques has broadened the scope of electromyography, the essential principles relating to the collection of physiological data remain unchanged. The general arrangement of the material is, therefore, largely unaltered, the early chapters concerned with principles and technique, the later chapters with clinical applications. Sections that have been particularly expanded have been those dealing with quantitative methods, the electrical study of reflexes, spinal cord disease and radiculopathy. A new section on movement disorders has been added.

It is a pleasure to acknowledge the help received from many sources. Comments and suggestions from friends and colleagues have been particularly useful and we hope have been taken fully into account. We are grateful to Miss M. Benstead, medical artist Dundee University, who has provided a number of line drawings and to Mrs Norma Spain who has typed portions of the text. Figures 3.4 and 14.2 have been reproduced from the *Journal of Neurology, Neurosurgery and Psychiatry* and Figures 16.4 and 16.5 from the *Journal of Neurological Sciences*, and we are glad to acknowledge the courtesy of the authors and of the editors and publishers of these journals who have granted permission. In each instance the source has been acknowledged in the caption. Lastly we are grateful to Mr

Stephen Neal and the Pitman Medical Publishing Co. for their co-operation.

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Preface to the First Edition

The purpose of this book is to provide a concise account of clinical electromyography for those working in the fields of neurology, physical medicine, and orthopaedic surgery who are likely to find the methods of practical value. It is hoped that it will be useful to undergraduate and postgraduate students interested in these subjects, and also to practising physicians and surgeons who may be concerned with the management of neuromuscular disorders.

Together with electroencephalography, electromyography has developed out of neurophysiology, but it is only in the past two decades that it has become recognised as a separate discipline widely used in clinical diagnosis. The term electromyography was originally used to refer to the methods employed to record action potentials from human muscle fibres in health and disease. In recent years, the expression has had a wider use, and is now frequently used to refer to the whole range of electrodiagnostic techniques as they are applied to peripheral nerve and muscle. It is in this sense that the expression is used in the title of this book. The field is a growing one and includes, apart from electromyography in the strict sense, the techniques of neuromuscular stimulation, which were found to be of particular value in the war years in the investigation of peripheral nerve injuries. In the past decade the study of peripheral neuropathies has been enlarged and clarified by developments in nerve conduction velocity measurement. At the same time there has been increasing interest in quantitative methods of electrodiagnosis which have contributed to the development of more objective tests.

The first six chapters contain a description of the methods and apparatus used. In this section the standard methods in general use are described, but more recent quantitative methods are also considered and an attempt has been made to indicate some of the underlying physiological principles. The remaining chapters are devoted to a review of some of the clinical conditions where electrical diagnostic methods may be of value. In these sections the purpose has been to indicate the circumstances in which electromyography may be useful, to select appropriate techniques, and to discuss the significance and limitations of the findings. The emphasis throughout has been clinical and the role of electromyography in studying the action of particular muscles in the control of posture and movement has not been discussed. The subject matter has been confined to the study of peripheral nerve and muscle, and no mention has been made of the electrical activity of the brain which belongs to the separate discipline of electroencephalography. The terminology used has been largely based on the recommendations in the Pavia Committee on Electromyography Subcommittee Report (Simpson, 1969).

The book as a whole is intended as a practical guide and not an exhaustive review, and no attempt has been made to include a complete bibliography. It is hoped, however, that sufficient references are given to provide the reader with some access to original sources. Although we have tried to draw, wherever possible, from personal experience we cannot but be conscious of our debt to others, particularly to those who have carried out the studies on which present knowledge is based.

In particular we are grateful to Professor J. A. Simpson for contributing the Foreword, for reading the manuscript, for providing Fig. 13.1 and Fig. 14.1, and many helpful suggestions. We should like to thank Dr Michael Robertson and Dr Alison Fleming for reading portions of the manuscript. The ocular electromyograms were carried out with the collaboration of Dr I. M. Strachan and Dr D. K. Whyte. The electromyographic and nerve conduction recordings were made with the technical assistance of Mrs Catherine Kinnear. The work of preparing the manuscript was carried out by Miss Joan Lindsay and Mrs Margaret Macalister, and many of the illustrations were prepared with the assistance of Mr Robert Cochrane and Mr Michael Anderson. We are glad to acknowledge the courtesy of the Medical Research Council and H.M. Stationery Office for permission to reproduce previously published material and the editors of the Proceedings of the Royal Society of Medicine for permission to reproduce Fig. 11.2.

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Contents

1 Electrodiagnostic Methods: Their Background and Application

Although electrodiagnostic techniques for the study of nerve and muscle have developed out of electrophysiological methods established in the course of the past hundred years it is only since the Second World War that they have achieved widespread use in clinical diagnosis. Detailed accounts already exist of the historical background (Licht, 1971; Buchthal and Rosenfalck, 1966).

Since nerve and muscle are inaccessible from the surface, their function can be studied only by the recognition of appropriate clinical signs. The application of procedures of electrical stimulation and recording depends on known physiological features of transmission and excitability and allows additional physical signs to be elicited which, in many instances, are objective and exact. At present, the procedures in use fall into two categories: (1) The artificial electrical stimulation of nerve and muscle by means of applied electric currents, and (2) the recording of the potentials that occur when nerve and muscle are active.

The electrical stimulation of nerve and muscle has given rise to two techniques. First, there is the application of stimulation techniques to determine the excitability of the tissue under study. Since muscle is normally excited through its motor nerve, and since nerve and muscle differ in their excitability, this method has been of value in deciding whether or not a muscle is properly innervated. Many different techniques have been developed to show this difference in excitability. At present, the test most commonly used is to plot the strength or intensity-duration curve using a stimulator that will produce rectangular pulses of known amplitude and duration (*see* Chapter 7). This form of test was first described in 1916 by Adrian, but the clinical application depends on the much earlier observation that denervated muscle will respond to galvanic (long duration) shocks but not to faradic (short duration) shocks. Before the advent of electronic stimulators the galvanic-faradic test, which could be performed with simple apparatus, was widely practised.

More recently, the measurement of 'accommodation', the property of excitable tissues to oppose or resist a gradually increasing stimulus, has become practicable as a clinical procedure with modern electronic apparatus (*see* Chapter 8). Here again, normal and denervated muscle can be distinguished quantitatively.

A further application of stimulation techniques has been the measurement of conduction velocity along peripheral nerves (*see* Chapter 5). This was first accomplished by Helmholtz (1850) but its clinical application was not recognised until animal experiments (Berry *et al.*, 1944; Sanders and Whitteridge, 1946) showed that conduction velocity is slowed in nerves regenerating after nerve injury. This method has since been widely applied to the study of peripheral nerve disorders.

The recording of potentials when nerve and muscle are active includes the study of evoked potentials, which are regularly recorded during nerve conduction measurements, and the study of action potentials that arise in muscle during spontaneous or voluntary activity. Although human action potentials had already been recorded many years previously, the earliest extensive study of the human electromyogram was made by Piper (1912), who recorded potentials during voluntary contraction using surface electrodes and a string galvanometer. With modern apparatus, this technique has provided much information regarding the anatomy and mode of action of different muscles in the body. In 1929, Adrian and Bronk introduced the concentric needle electrode which made it possible

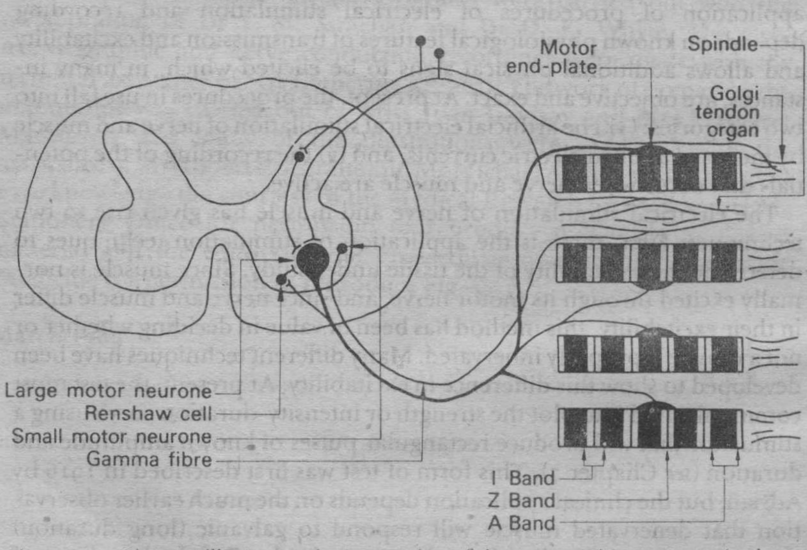

Figure 1.1 Diagram illustrating the innervation of the motor unit. Large anterior horn cells are shown supplying four striated muscle fibres. Muscle spindles lie in parallel with the muscle fibres, and afferents from the spindles act on the large motor neurones through a single synapse. The intrafusal muscle fibres within the spindles receive motor innervation from the small neurones in the spinal cord through the gamma efferents. The golgi tendon organs lie in series with the striated muscle fibres and make connection with the anterior horn cells through a single internuncial neurone.

to study the action potentials of motor units and of single muscle fibres. Together with the development of the cathode-ray oscilloscope and electronic recording apparatus this made it possible for electromyography to develop as a clinical method (*see* Chapter 2).

These techniques form the basis of electrodiagnosis as it exists today. In recent years, many refinements have been developed, and in many instances quantitative analysis of the data obtained has become possible. Essentially, they all clarify different aspects of the functioning of the motor unit and in this way assist understanding the disordered physiology of nerve and muscle.

The Motor Unit

The motor unit consists of an 'individual motor nerve cell and the bunch of muscle fibres it activates' (Sherrington, 1929). This complex, which consists of the nerve cell, the nerve fibre and its terminal branches, the neuromuscular junctions, and the muscle fibres and their constituent myofibrils, is the final pathway through which nervous activity gives rise to voluntary movement (Fig. 1.1). The function of electromyography is to study the integrity of different portions of the motor unit; at present it provides little information regarding the central activation of the motor units although electrical methods have been applied to the study of reflex action.

THE MOTOR UNIT POTENTIAL

When a muscle is explored with a concentric electrode and action potentials are recorded during a voluntary contraction, the potentials recorded are generally described as motor unit potentials. They represent potentials derived from groups of muscle fibres that are contracting nearly synchronously, and are situated fairly close together and frequently activated by a single neurone. A single electrode will record from a limited number of fibres only, and the action potential represents the summated potentials derived from up to about thirty fibres in the vicinity of the electrode tip (Buchthal, 1960). The motor units of the limb muscles generally contain a substantially larger number of fibres than this, and studies in which the spatial distribution of the potentials arising from a single unit has been measured with a multilead electrode indicate that the fibres of a unit are distributed over 5 to 10 mm of the cross section of the muscle (Buchthal *et al.*, 1959). The motor unit potential therefore represents a sample of the activity of the fibres of the motor unit, and its characteristics must therefore be influenced by the position of the electrode in relation to the fibres of the unit.

MOTOR UNIT SIZE

An approximate measure of the size of motor units within a muscle is