ELECTROMYOGRAPHY IN GENERAL ANAESTHESIA

BY

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A PRIMARY objective of general anaesthesia is to depress skeletal muscular responses sufficiently for smooth completion of a surgical procedure. The drugs used for this purpose are either general depressants of the central nervous system or selective depressants of motor impulse transmission to striated muscle. In both cases the extent of the depression of skeletal muscle activity is a principal guide to administration of the drugs in question, particularly as observed in the effect on respiration and on abdominal wall tension.

Changes in the electrical activity of skeletal muscles are observable in the electromyogram (e.m.g.), and since there is close proportionality between electrical activity and mechanical tension under many conditions (Lippold, 1952; Bigland and Lippold, 1954; Bergström, 1958), the e.m.g. can indicate the force of contraction of a muscle or conversely its degree of relaxation. There is thus a physiological basis for the use of electromyography in measuring the striated muscle response to surgical stimulation and its depression by anaesthetic drugs. The practical scope of the method has been the subject of three years study in the operating room. A summary of the experience gained is presented here, preceded by a brief historical survey.

HISTORICAL NOTES

The generation of electricity by contracting muscle was demonstrated by Matteucci in 1838, and DuBois-Reymond (quoted by Morgan, 1868) observed action currents from the arm muscles of a man as far back as 1851. Electromyographic recording was pioneered by Piper in 1907 (Piper, 1912) after Einthoven's invention of the string galvanometer (Einthoven, 1901), an instrument sufficiently sensitive to record the minute voltages involved, but lacking an adequate frequency response. This deficiency was overcome with the introduction of the cathode ray oscilloscope into biology by Gasser and Erlanger (1922). Electronic amplification (in conjunction with a galvanometer) had been originated by Forbes and Thacher in 1920.

Until 1929 human electromyograms were obtained with surface electrodes, recording the collective activity of relatively large portions of muscle. A notable increase in resolving power occurred when Adrian and Bronk (1929) designed the coaxial needle electrode, by means of which potentials from a single motor unit could be recorded. Adrian adopted the loudspeaker as an aid to electromyography, utilizing the ability of the ear to discern differences in intensity and quality not distinguishable in a graphic record.

Electromyography was seldom practised clinically before 1944, when Weddell, Feinstein and Pattle published a comprehensive report which stimulated considerable interest. Integrated electromyography devised in 1952 by Inman and co-workers and by Lippold (1952) provides a comparative measure of the electrical activity of a muscle. The technique was described in relation to anaesthesia in 1960 by Fink and his colleagues.

TECHNIQUE

An electromyograph amplifier must have a higher frequency response than an electrocardiograph because the action potentials from a striated muscle fibre are much briefer than the waves in an electrocardiogram. When recorded with surface electrodes, the electromyogram is more attenuated and its site of origin more uncertain than if needle-point electrodes are used, inserted directly into the muscle. The closer the electrodes are to each other,
the less the likelihood of interference from electrocardiographic potentials. In practice, unipolar needles often give better results than concentric electrodes. The field of sampling is a sphere of only a few millimetres radius, since the amplitude of the recorded potential falls by 90 per cent within 4 mm of an active fibre (Buchthal, Guld and Rosenfalck, 1957a). Artefacts due to surgical manipulations are infrequent. Interference transmitted by the hand of the anaesthetist is avoided if he wears a rubber glove.

THE INTEGRATED ELECTROMYOGRAM

The irregular pattern in an e.m.g. results from overlapping territories and asynchronous contraction of different motor units. Each unit is dispersed in subgroups (subunits) of up to thirty muscle fibres over a diameter of some 5 mm (Buchthal, Guld and Rosenfalck, 1957b). The intensity of the electrical activity is difficult to estimate in the standard e.m.g. but can be conveniently observed on an oscilloscope with the aid of an integrating circuit (Fink and Scheiner, 1959) or with an averaging circuit, such as a peak detector (Inman et al., 1952). An integrator may be compared to a bath with the plug in: inflow can be measured by the rate at which the pressure on the bottom rises. A peak detector, on the other hand, corresponds to a bath with the plug removed: an equilibrium develops between inflow and outflow, the equilibrium pressure being an index of the rate of inflow. The integrator is more exact but must be discharged periodically in order to avoid "overflow". The peak detector only gives a rough "envelope" or "average" of the inflow activity but with the advantage of being observable continuously. This is the more practical method for clinical purposes (fig. 1) and a compact electromyoscope of this type, available commercially,* has been designed, utilizable with both flammable and non-flammable agents.

ELECTROMYOGRAPHY OF ABDOMINAL MUSCLES

The e.m.g. of the oblique-transverse group of abdominal muscles is conveniently recorded by inserting electrode needles or wires between the costal margin and anterior superior spine of the ilium. After penetration of the deep fascia, any activity present in the external oblique is immediately recognized in the oscilloscope. If needle electrodes are used, the outer ends must be protected from pressure. With reasonable care no complication arises. The only one encountered was due to an ill-advised attempt by the author to remove electrodes while a patient was lying on them—by pulling on the leads. The fragments were extracted with a red face.

Electrical activity of the abdominal muscles is a usual finding in lightly anaesthetized patients. It has been observed with cyclopropane, ether, halothane, ethylene, tribromethanol, nitrous

*Manufactured by Electronics for Medicine, White Plains, New York, U.S.A.

FIG. 1
Abdominal electromyogram. Onset of paralysis during spontaneous respiration with nitrous oxide, oxygen and thiopentone anaesthesia. Lower trace. Standard e.m.g. Upper trace. Peak-detected e.m.g. Suxamethonium 20 mg was administered intravenously before the start of the record. Abdominal muscle activity during inspiration is less intense and blocked more rapidly than the activity during expiration. Time lines: 1 second.
oxide, and thiopentone (Fink, 1960). Some activity is also frequently present before anaesthesia in patients who have received a barbiturate or narcotic drug. It is often found in persons who have received no drug at all (8 out of 12 subjects examined).

The activity of the abdominal obliques generally varies reciprocally with that of the diaphragm, increasing in expiration and waning during inspiration. Decreased abdominal activity during inspiration is probably due to rhythmic inhibition from the respiratory centre, since it ceases as soon as the diaphragm is inactivated by overventilation (fig. 2). The abdominal muscle activity can be regarded primarily as a strong postural contraction rhythmically inhibited during inspiration, or, less probably, as a weaker postural contraction rhythmically increased during active expiration. A third view has been that the increased activity during expiration is a reflex response to falling abdominal pressure resulting from ascent of the diaphragm (Campbell, 1958). Why such a reflex should disappear during overventilation is not clear. The postural activity tends to be increased by surgical stimulation and by hypercapnia and is diminished by anaesthetics, by hypoxia, and by muscle relaxants.

It is principally in order to limit the troublesome postural contraction that muscle relaxants are administered at abdominal operations. The integrated abdominal e.m.g. shows the extent of the residual postural activity and constitutes a practical guide to the administration of muscle relaxants at such operations (Fink, 1960). This guide is particularly useful when respiration is managed with a mechanical ventilator. At such times the anaesthetist is deprived of information concerning the rhythmic and postural behaviour of respiratory muscles, ordinarily transmitted to his hand through the breathing bag. The integrated abdominal e.m.g. substitutes for and indeed improves on the bag, inasmuch as the eye may see changes in the oscilloscope 30 seconds or more before the hand becomes aware of them in the bag. In this respect the ear is even more sensitive than the eye: monitoring the e.m.g. with a suitably muted loudspeaker is truly one of the most pleasant, though rather esoteric, procedures of anaesthesia. Each type of abdominal movement—cough, hiccough, gag, breath-holding, attempt to get off the table—makes its own characteristic warning noise.

The anaesthetist can regulate muscle activity centrally with general depressants or peripherally with myoneural depressants. Either method is susceptible to electromyographic control but the e.m.g. does not distinguish between them, and is accordingly unsafe as a guide to anaesthetic depression when muscle relaxants are being used at the same time. On the other hand, electromyography has proved a safe guide to the administration of relaxants when a constant moderate level of anaesthesia is maintained. A principal clinical use for electromyography has been in regulating the administration of relaxants for abdominal procedures.

ELECTROMYOGRAPHIC REGULATION OF ABDOMINAL RELAXATION

This has been successful with nitrous oxide and oxygen supplemented by thiopentone and pethidine or 0.5 to 1 per cent halothane, and with 15 per cent cyclopropane in oxygen (Fink, 1960).

Complete electrical silence of the abdominal obliques is not necessary for adequate relaxation. Entirely satisfactory operating conditions often prevail in the presence of quite strong electrical activity (fig. 1). As the effect of the relaxant wears off and muscle tension returns, the activity gradually increases and eventually more relaxant drug becomes necessary. The reference level is established by noting the electrical activity when tension first becomes detectable. Strictly speaking, the tolerable level of activity must be determined empirically for each patient. However, it does not vary much from one patient to another, and in practice the same reference level can be used for most cases. Approach to this level in the integrated e.m.g. serves as a warning that more drug will soon be required. Intensification of the activity is gradual and usually extends over several minutes, so that adequate time for preventive treatment is available. With a short-acting drug like suxamethonium, a fixed dose of say 50 mg may be injected and the duration of action determined from the interval between approaches to the critical e.m.g. level. When observed by this method, the average requirement for suxamethonium in prolonged abdominal operations was found to diminish progressively from 360 mg.
Respiratory variations of the electromyogram during four successive increases in controlled ventilation. The traces from above down are (1) airway pressure, upward deflection denotes increase; (2) e.m.g. of diaphragm; (3) e.m.g. of abdominal oblique. Note the reciprocal activation of the diaphragm and the abdominal wall muscles (extreme left). Hypocapnoea abolishes rhythmic activity in both the diaphragm and the abdominal wall; postural contraction of the external oblique persists (extreme right). Time lines: 1 second. Female, halothane, nitrous oxide and oxygen anaesthesia.

per hour at the onset to about 150 mg per hour four hours later. The reason for this decrease is not clear. Accumulation of succinyl-monocholine, onset of so-called dual block (Churchill-Davidson, Christie and Wise, 1960) decreased stimulation, or even accommodation to surgical stimuli may play a part. It should be mentioned that tachyphylaxis to succinamethonium seems to result when muscles are stimulated by supramaximal electric shocks (Poulsen and Hougs, 1957).

DIFFERENTIAL DIAGNOSIS OF APNOEA

Three varieties of apnoea can be distinguished with the aid of abdominal electromyography. Breath-holding, as in a Valsalva manoeuvre or in laryngeal spasm, is characterized by strong continuous activity of the abdominal wall muscles. By comparison the activity during hypocapnic apnoea is continuous, but weak. On the other hand, in apnoea due to neuromuscular block, there is absence of activity if the block is complete, although traces of the respiratory rhythm remain if the block is partial.

ELECTROMYOGRAPHY OF THE HUMAN DIAPHRAGM

The technique introduced by Nieporent in 1956 is safe and simple. The exploring electrode is inserted through a lower intercostal space, at a distance of two to three inches from the costal margin in order to avoid the slips of origin of the abdominal wall muscles. The needle first makes contact with the lower rib and then is pointed upward and advanced through the intercostal muscle and costophrenic sinus, preferably during expiration. The intercostal usually is found to exhibit activity throughout the respiratory cycle. When the diaphragm is entered a sharp increase in activity occurs with inspiration, while the activity in expiration diminishes or disappears. The diaphragm technique has been used in over fifty patients; there have never been any sequelae.

Electrically the diaphragm is an extension of the respiratory centre. By observing the cessation and return of e.m.g. activity during alternating over- and under-ventilation, the respiratory threshold tension of carbon dioxide can be determined. In end-expiration it was found to lie between 38 and 43 mm Hg with light thiopentone, nitrous oxide and oxygen anaesthesia (Fink et al., 1960) and slightly lower with halothane (Hanks, Ngai and Fink, 1961). The electrodes can be inserted through a local anaesthetic weal in unanaesthetized subjects and are well tolerated; however, in the waking state overventilation fails to define a respiratory threshold tension of carbon dioxide. This is attributable to the persistence of
a respiratory stimulus independent of carbon dioxide (Fink, 1961) and is apparently associated with cerebral activity accompanying wakefulness.

**COMBINED MONITORING WITH THE ELECTROMYOSCOPE**

It is interesting to note that the heart beat can be monitored simultaneously with the abdominal e.m.g. For this purpose the indifferent electrode is placed at some distance from the exploring electrode, for example at the shoulder. A large pulse due to the QRS wave is observed at each heart beat, with intervening smaller pulses emanating from abdominal muscle activity. Since the latter show the respiratory rhythm as well as the abdominal wall tension, all three functions are observable in a single monitor.

**SUMMARY**

Electromyography during general anaesthesia has a distinct sphere of usefulness, particularly in conjunction with mechanically controlled ventilation. The integrated electromyogram is an extremely sensitive guide to changes in respiratory and tonic activity of the abdominal muscles. It constitutes an interesting adjunct to close observation of surgical patients in the operating room.

**REFERENCES**


