Clinical Use of Peripheral Nerve Stimulators

D. OSTERGAARD, J. VIBY MOGENSEN

Introduction

Evaluation of degree of neuromuscular blockade during anaesthesia is often based solely upon clinical observations such as occurrence of spontaneous movements, bucking and swallowing, or testing of clinical signs such as the ability to open eyes and sustain headlift. The clinical evaluation is, however, not always adequate. Thus, in two studies on the frequency of residual curarisation in the recovery room it was found that the neuromuscular blockade was insufficiently reversed in 24-44% of patients given a non-depolarizing relaxant and not monitored with a nerve stimulator during anaesthesia[1,2].

The increased awareness of the risk of residual curarisation and the development of the new non-depolarizing relaxants, Atracurium and Vecuronium, with a rapid spontaneous recovery rate, have increased the interest in simple methods for evaluation of neuromuscular blockade. Equipment for mechanical and electromyografic (EMG) monitoring of the response to nerve stimulation has become commercially available[3,4]. Unfortunately, this equipment is expensive and rather cumbersome to use in daily clinical routine. However, one can manage quite well without such sophisticated equipment, i.e. with only a nerve stimulator.

The purpose of this review article is to discuss the principles of peripheral nerve stimulation and the clinical use of nerve stimulators without recording equipment.

Patterns of Nerve Stimulation

The neuromuscular function is monitored by stimulation of a peripheral motor nerve and evaluation of the response of the skeletal muscle innervated by that nerve.

Three different types of stimulation are used, i.e. single twitch, tetanic and train-of four (TOF) stimulation[5].

Single Twitch Stimulation

Single supramaximal current impulses are applied at frequencies of 0.1 to 1.0 Hz. The response to single twitch stimulation depends on the frequency with which the individual stimuli are applied. During a non-depolarizing block, the twitch response will decrease if the stimuli are given more than every 6-10 sec[6]. Therefore a 0.1 Hz frequency is often used during anaesthesia. The 1.0 Hz stimulation shortens the time necessary to obtain supramaximal stimulation and can be used during induction of anaesthesia. Supra-maximal stimulation is necessary to ensure activation of all muscle fibers.

Tetanic Stimulation

In clinical practice the frequency most commonly used is 50 Hz, given for 5 s. Some use higher frequencies e.g. 100Hz, but a frequency above 50 Hz is unphysiological, since a 50 Hz tetanic stimulation stresses the neuromuscular junction to the same extent as does a maximal voluntary effort[7]. During normal neuromuscular transmission the response to tetanic stimulation is sustained (fig.1). The decrement in acetylcholine release caused by the tetanic stimulation does not cause fade because the release of acetylcholine is many times greater than necessary to evoke a response (margin of safety). Following a non-depolarizing neuromuscular blocking agent the decrease in acetylcholine output during the tetanic stimulation will be manifested by a non-sustained response (fade). The degree of fade depends first of all upon the degree of neuromuscular blockade, but also upon the frequency (50 or 100 Hz) and duration of stimulation is applied. A tetanic stimulation must not be applied more often than every 6 min[8,9].

When a tetanic stimulation is combined with single twitch stimulation applied both before and after the tetanic stimulation an increased post-tetanic twitch response (PTF, PTP) is oberved

Dr D. Oestergaard, M.D. Assistant in Anaesthesia, Associate Professor J. Viby Mogensen M.D. Ph.D.
Department of Anaesthesia Glostrup Hospital Herlev Hospital University of Copenhagen, DK 2730 Herlev, Denmark.

during non-depolarising blockade. This is due to a post tetantic increase in mobilisation and synthesis of acetylcholine, which remain increased for some time after the tetanic stimulation. The increased posttetanic twitch respone returns to pretetanic levels when the acetylcholine mobilisation returns to pretetanic levels. During intense neuromuscular blockade the number of posttetanic responses can be counted (see later). This is called the posttetanic count or PTC. For each non-depolarizing relaxant an inverse correlation exists between PTC and time to first reaction to train-of-four nerve stimulation[10].

Train-of-four Stimulation

Train-of-four (TOF) nerve stimulation is a short train of four supramaximal stimuli applied at intervals of 0.5 s over a period of 2 s (2 Hz)[9, 11, 12]. The TOF stimuli are normally repeated every 10-12 s (fig 2). The amplitude of the fourth response in relation to the first is called the TOF ratio and is used as an index of the degree of non-depolarizing blockade. The TOF ratio is reduced following administration of a non-depolarizing relaxant, and is inversely proportional to the degree of the neuromuscular block. TOF stimulation is less painful than a tetanic stimulation, and the neuromuscular block remains uninfluenced by the stimulation. Contrary to the response to single twitch stimulation, the response to TOF stimulation can be evaluated without a prior control response.

The Nerve Stimulator

Several different nerve stimulators with different characteristics are available for clinical use. There are, however, some important demands on a nerve stimulator. The stimulator should be handy and simple to use and it should be able to give the following patterns of stimulation: TOF, single twitch stimuli at frequencies of 0.1 and 1.0 Hz and a tetanic stimulation of 50 Hz. Ideally the nerve stimulator should have an inbuilt time-constant system to facilitate the use of the PTC method. The response to tetanic and posttetanic stimulation depends on the frequency and duration of the tetanic stimulus and the time lapse between the conclusion of that stimulus and the first posttetanic single stimulus. It is therefore essential to keep these variables constant. The duration of the tetanic stimulus should be 5 s and the first posttetanic twitch stimulation should follow 3 s later.

The nerve stimulator should be a constant current stimulator. This means that the current to the stimulated nerve will be unchanged irrespective of changes in impedance between the electrodes[5]. In our department, a Myotest nerve stimulator[13] is used for routine anaesthesia (fig. 3). The Myotest is battery operated and very simple to use. It has the above mentioned patterns of stimulation and an inbuilt electronically controlled time-constant system which makes it possible to compare the neuromuscular response to tetanic and post-tetanic stimulation at different times during anaesthesia. The nerve stimulator gives a unipolar current impulse with an adjustable amplitude from 0-61 mA.

Placement of the Electrodes

Commonly the ulnar nerve is used for stimulation, but other peripheral nerves can be used as well, i.e. the facial nerve, the posterior tibialis nerve or the peroneal nerve. Stimulation of the ulnar nerve results in thumb adduction as the short adductor pollicis muscle is the only muscle innervated by the ulnar nerve acting at the thumb. For evaluation of the response, the arm is ideally placed in 90% abduction with the hand in supination. The skin should be properly cleansed before placing the electrodes. It is essential to place the electrodes so that nerve and not muscle is stimulated (fig. 3). Surface, i.e. rubber or disposable e.c.g. electrodes, or needle electrodes may be used. Needles are to be prefered in obese patient and in patients with very cold extremities. The impedance of rubber electrodes increases with time, especially if they are not properly cleaned after each use. Therefore, they should not be allowed to get too old.

Evaulation of the Response to Nerve Stimulation

The response to peripheral nerve stimulation can be evaluated visually, or by touch. In our department we prefer to evaluate the response of the thumb by touch, mainly because in this way the chance of direct muscle stimulation is less.

Following an intubation dose of a non-depolarizing relaxant three phases of levels of neuromuscular blockade can be recoginized (fig. 4): A phase of intense blockade, a phase of moderate or surgical blockade and a recovery phase. A few minutes after injection of relaxant the response to single twitch and TOF stimulation disappears for a period of time, the duration of which depends on the relaxant and the dose used. This period of intense blockade is called "period of no response". It is possible to quantify a part of this period by applying a tetanic stimulation and counting the number of twitches (the PTC) following the tetanic stimulation[10].

Tetanic and post-tetanic stimulation

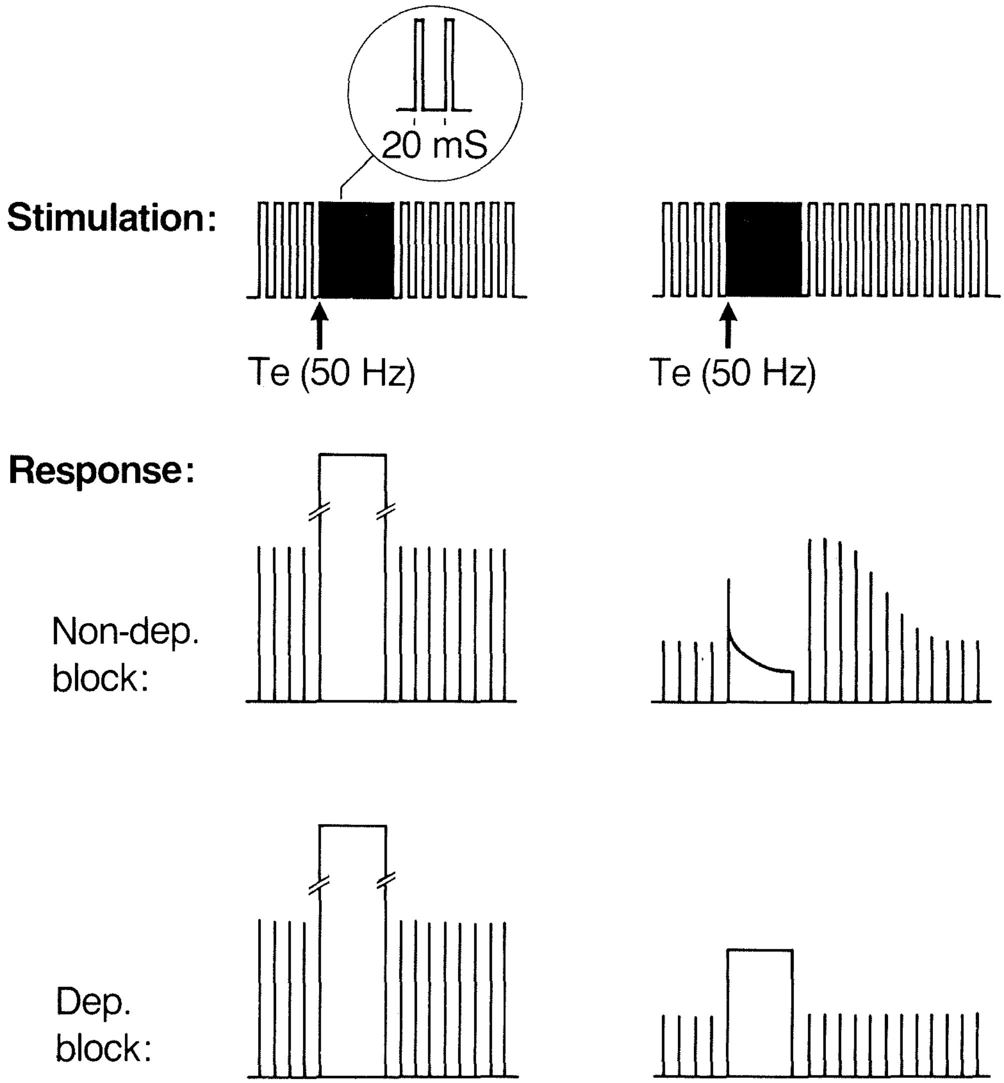


FIG. 1 illustrates a diagrammatic illustration of the evoked response to tetanic and post-tetanic twitch stimulation following injection of a non-depolarizing and a depolarizing myoneural blocking drug. From J. Viby-Mogensen 1984 with kind permission of Boerhaave Committee for Postgraduate Medical Education.

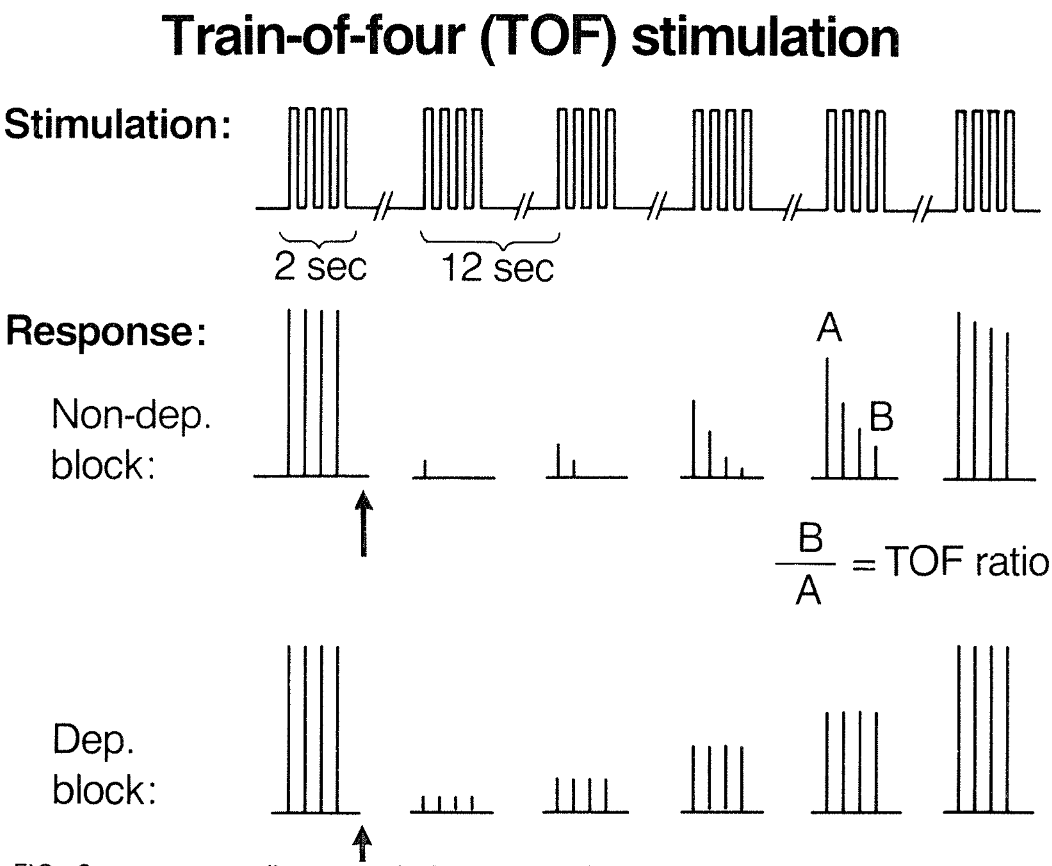


FIG. 2. presents a diagrammatic illustration of stimulation pattern and the evoked response to train-of-four (TOF) nerve stimulation. Arrows indicate injection of myoneural blocking agent. From J. Viby-Mogensen 1984 with kind permission of Boerhaave Committee for Postgraduate Medical Education.

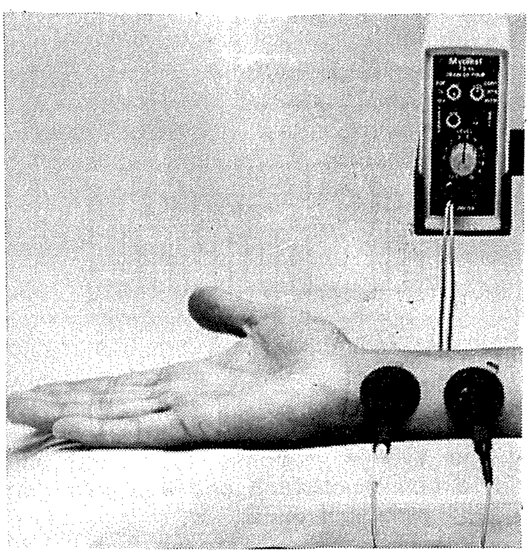
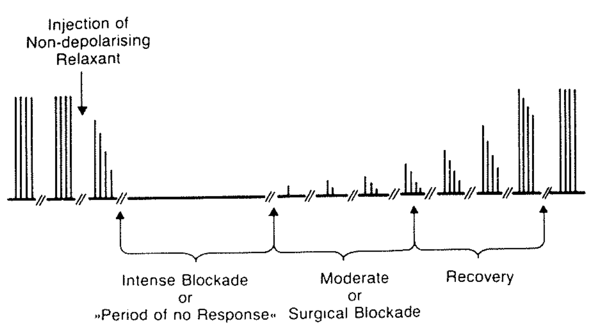


FIG. 3 represents monitoring of neuromuscular ◀ blockade without recording equipment. A myotest nerve stimulator and surface electrodes are used.

FIG. 4 presents a diagrammatic illustration of the changes in response to train-of-four (TOF) nerve stimulation during non-depolarizing neuromuscular blockade. From J. Viby-Mogensen 1985 (5) with kind permission of Clinics in Anaesthesiology. ▼



There is a good correlation between a PTC and time to first response to TOF for any given relaxant. Following pancuronium 0.1 mg/kg, for instance, the response to post-tetanic twitch stimulation appears an average of 37 minutes before the first reaction to TOF stimulation. Fig. 5 shows the time to first reaction to TOF as a function of the number of posttetanic responses felt at the thumb at any given time(10). Following atracurium and vecuronium the response to posttetanic twitch stimulation appears about 10 minutes before the first response to TOF stimulation(14).

Following the period of no response is the phase of surgical or moderate blockade, characterized by a gradual return of the four responses to TOF (fig.6). A relationship exists between the number of responses to the TOF stimulation and the degree of neuromuscular blockade. When only one response to TOF stimulation can be felt the degree of neuromuscular blockade is 90-95%. If all four responses are present the degree of blockade is less than 75% (15).

During recovery phase all four responses to TOF stimulation are present and the height of the fourth in relation to the first response gives the TOF ratio. A ratio of 0.7 is normally taken to reflect adequate recovery(16). It is, however, important to realise the uncertainty in estimation of a TOF ratio without monitoring equipment. It is not possible by touch to decide whether a TOF ratio is 70, 60 or 50%. Only when the ratio is 40% or below can fade be felt with certainty(17).

Correlation Between Response to Nerve Stimulation and Clinical Parameters

When only one response to TOF stimulation can be felt – corresponding to about 10% twitch height – the degree of neuromuscular blockade is sufficient for most surgical procedures.

However, at this level of peripheral blockade respiratory movements, cough or hiccup may occur, because the respiratory muscles are less sensitive to relaxants than the peripheral muscles(18). Therefore, when it is mandatory that the patient does not cough and no spontaneous movements take place, the block has to be more intense. In such cases, the level of blockade can be evaluated by the PTC method. To ensure that the respiratory muscles as well as the peripheral muscles are totally paralysed, the degree of peripheral block has to be so intense that no response can be elicited to post tetanic twitch stimulation (PTC = 0) (Viby-Mogensen, unpublished observation).

In the recovery phase the TOF ratio is used as an index of recovery. At a TOF ratio of 0.60 the patient is able to maintain headlift for 3 sec. A TOF ratio of 0.70 correlates well with clinical signs of adequate recovery: The patient will be able to sustain headlift for 5 sec., protrude tongue, open eyes and cough sufficiently(19).

Clinical Use

In our institution nerve stimulators are used routinely whenever relaxants are given(20). When the patient is prepared for anaesthesia, the electrodes are placed at the wrist (fig. 3). The nerve stimulator is, however, not switched on until the patient is asleep. 1.0 Hz single twitch stimulation is used to obtain supramaximal stimulation. Hereafter, the stimulation is changed to TOF stimulation (fig. 7). Following injection of relaxant, the trachea is intubated about 30 sec. after the response to nerve stimulation has disappeared. If a non-depolarizing relaxant is used, the degree of neuromuscular blockade is evaluated by the method of PTC during the succeeding period of intense blockade. In this way, time to reappearance of the first response to TOF can be calculated, if necessary.

During the phase of surgical relaxation, TOF stimulation is used. We aim at keeping the block at a level, so that always one or two responses to the TOF stimulation are present. If a more intense level of blockade is needed for surgical reasons, the degree of blockade is again evaluated by the PTC method.

Reversal of a non-depolarizing block is normally possible when the first response in the TOF is felt. We do not therefore try to reverse the block before one and preferably two responses in TOF are felt. The reversal time is influenced by the magnitude of block at the time of injection of cholinesterase inhibitor(21). If all responses to TOF stimulation are present, corresponding to about 25% twitch height recovery, reversal with neostigmine is always possible within 10 minutes. If no response to TOF stimulation can be felt, reversal will often be inadequate irrespective of dose of neostigmine used.

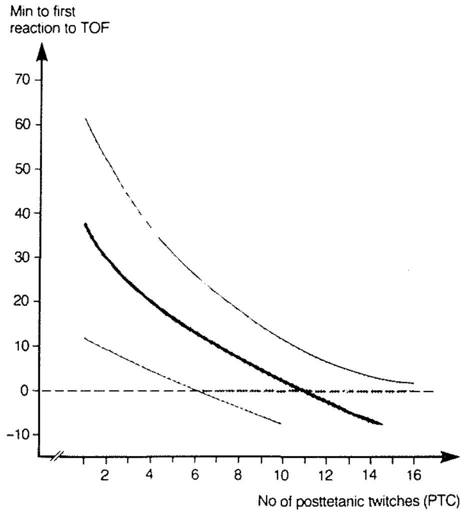


FIG. 5 illustrates the relationship between minutes to first reaction to train-of-four (TOF) and number of posttetanic twitches felt at the thumb (the posttetanic count: PTC). From J. Viby-Mogensen 1984 with kind permission of Boerhaave Committee for Postgraduate Medical Education and Excerpta Medica.

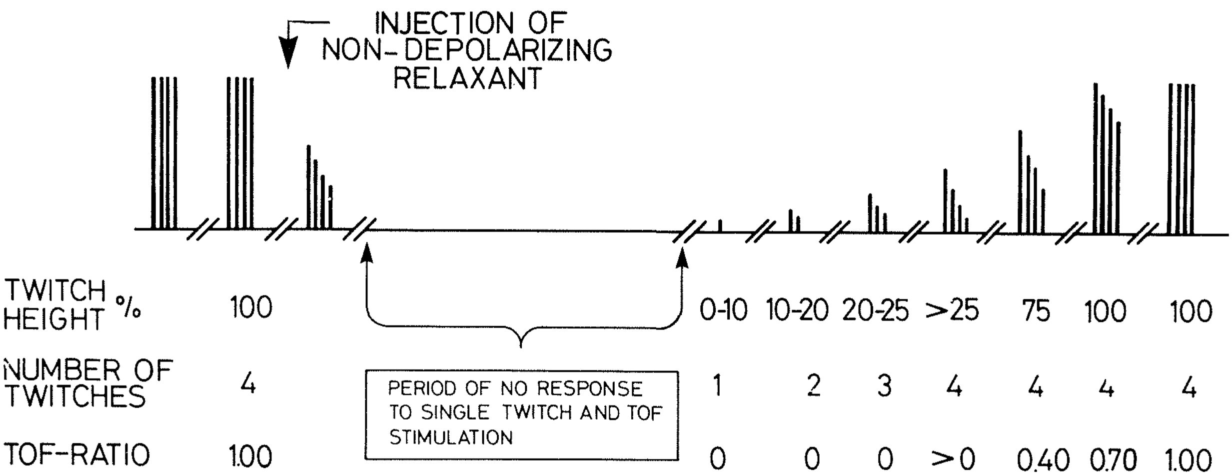


FIG. 6 presents a diagrammatic illustration of the relationship between the evoked response to single twitch (0.1 Hz) and train-of-four (TOF) nerve stimulation during non-depolarizing neuromuscular blockade, see text for further explanation. From J. Viby-Mogensen (1982) (4) with kind permission of Br J. Anaesth.

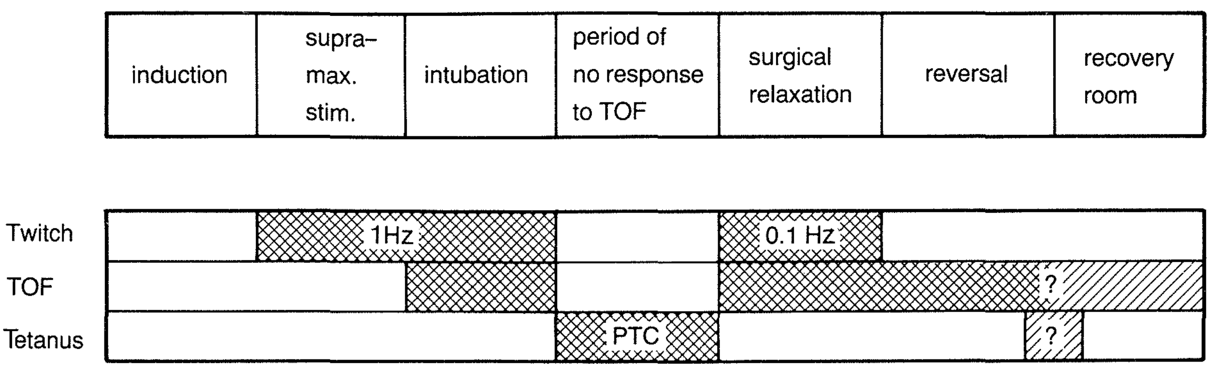


FIG. 7 represents a diagrammatic illustration of the times when different patterns of nerve stimulation are used in clinical routine at Herlev University Hospital, Copenhagen. TOF = train-of-four nerve stimulation, PTC = post-tetanic count. From J. Viby-Mogensen (1983) (18) with kind permission of Excerpta Medica.

Conclusion

Because of the difficulties in estimating a TOF ratio visually or by touch we never evaluate degree of recovery solely on the basis of the TOF response. The clinical signs of adequate recovery are always used as well.

By applying a nerve stimulator before induction and using it throughout anaesthesia overdose of relaxants can be avoided and safe reversal performed. Potentially life threatening residual curarisation can therefore be avoided.

References

1. **Viby-Mogensen J., Chraemmer-Jorgensen B., Ording H.** Risidual curarisation in the recovery room. Anesthesiology 1979; 50: 539-41.
2. **Lennmarken C., Lofstorm J.B.** Partial curarisation in the postoperative period. Acta Anaesthesiol Scand 1984; 28: 260-62.
3. **Ali H.H., Savarese J.J.** Monitoring of neuromuscular function. Anesthesiology 1976; 45: 216-43.
4. **Viby-Mogensen J.** Clinical assessment of neuromuscular transmission. Br J Anaesth 1982; 54: 209-23.
5. **Viby-Mogensen J.** Clinical measurement of neuromuscular function: An Update Clinics in Anaesthesiology 1985; 3: 467:82.
6. **Lee C. Katz R.L.** Neuromuscular pharmacology. A clinical update and commentary. Br J Anaesth 1980; 52: 173-88.
7. **Merton P.A.** Voluntary strength and fatigue. J Physiol 1954; 123: 553.
8. **Gissen A.J., Katz R.L.** Twitch, tetanus and posttetanic potentiation as indices of nerve-muscle block in man. Anesthesiology 1969; 30: 481.
9. **Ali H.H., Utting J.E., Gray C.** Stimulus frequency in the direction of neuromuscular block in humans. Br J Anaesth 1970; 42: 967-78.
10. **Viby-Mogensen J., Howardy-Hansen P., Chrammer-Jorgensen B.** Posttetanic count (PTC): A new method of evaluating an intense non-depolarizing neuromuscular blockade. Anesthesiology 1981; 55: 458-61.
11. **Ali H.H., Ytting J.E., Gray C.** Quantitative assessment of residual antidepolarizing block (part 1). Br J Anaesth 1971; 43: 473-77.
12. **Ali H.H., Ytting J.E., Gray C.** Quantitative assessment of residual antidepolarizing block (part 2). Br J Anaesth 1971; 43: 478-85.
13. **Viby-Mogensen, J., Hansen P.H., Chraemmer-Jorgensen B., Ording H., Kann T., Fries B.** A new nerve stimulator (Myotest). Br J Anaesth 1980; 52: 547-50.
14. **Viby-Mogensen J., Bonsu A.K., Fernando P.U.E., Muchhal K., Tamilarasan A., Lambourne A.** Monitoring of intense neuromuscular blockade caused by Atracurium. Br J Anaesth 1986; 58: 68 S.
15. **Lee C.M.** Train-of-four quantitation of competitive neuromuscular block. Anesth Analg 1975; 54: 649.
16. **Brand J.B., Cullen D.J., Wilson N.E. Ali H.H.** Spontaneous recovery from non-depolarizing neuromuscular blockade: Correlation between clinical and evoked responses. Anesth Analg (Cleve) 1977; 56: 55.
17. **Viby-Mogensen J., Jensen N.H., Engbaek J., Ording H., Skovgaard L.T., Chraemmer-Jorgensen B.** Tactile and visual evaluation of the response of train-of-four nerve stimulation. Anesthesiology 1985; 63: 440-43.
18. **Johansen S.H., Jorgensen M., Molbech S.** Effect of Tubocurarine on respiratory and non-respiratory musle power in man. J Appl Physiol 1964; 19: 990.
19. **Ali H.H., Kitz R.J.** Evaluation of recovery from non-depolarizing neuromuscular block, using a digital neuromuscular transmission analyzer. Preliminary report. Anesth Analg (Cleve) 1973; 52: 740.
20. **Viby-Mogensen J., Engbaek J., Jensen N.H., Chraemmer-Jorgensen B., Ording H.** New developments in clinical monitoring of neuromuscular transmission: Monitoring without equipment. Clinical experiences with Norcuron. Excerpta Medica 1983; 66-71.
21. **Katz R.L.** Clinical neuromuscular pharmacology of Pancuronium. Anesthesiology 1971; 34: 550-56.