EVALUATION OF MUSCULAR RELAXATION IN CONTROLLED RESPIRATION*

BY

V. A. KOVANEV AND YA. M. KHMELEVSKY

Institute of Cardiovascular Surgery, Moscow, U.S.S.R.

SUMMARY

A study of relaxation was made in 275 patients undergoing cardiac surgery (mainly mitral valvotomy) under light narcosis with controlled ventilation. Succinylcholine was used for intubation and was followed by tubocurarine or gallamine for the operation. On the basis of data obtained from stimulation of the motor nerves to muscles, electromyography, and the clinical picture, it is suggested that it is possible to subdivide the process of relaxation into stages. These stages would facilitate the control of relaxation during surgery and in the immediate postoperative period.

At the present time, surgical operations involving an open pneumothorax are often performed under light narcosis with muscular relaxation and controlled ventilation.

Despite an extensive literature on the subject, many aspects of the use and action of relaxants have not been studied adequately. One of the problems requiring further research is the question of control of the degree of the relaxation of the skeletal muscles during anaesthesia and surgery.

Muscular relaxation has not been divided into precise phases, although it is quite clear that the degree of curarization is of immediate practical interest to the anaesthetist, especially during prolonged intrathoracic operations. Usually, the effectiveness of a dose of a relaxant during artificial pulmonary ventilation is assessed by the time required for the restoration of diaphragmatic activity, in spite of the fact that recovery of respiration depends not only on recovery from curarization but also on the degree of depression of the respiratory centres caused by analgesics, narcotics, the level of blood carbon dioxide and other factors (Wylie and Churchill-Davidson, 1960; Churchill-Davidson and Wise, 1960; Churchill-Davidson, Christie and Wise, 1960; Churchill-Davidson and Christie, 1959; Churchill-Davidson, Christie and Wise, 1960; Churchill-Davidson and Christie, 1959; Churchill-Davidson, Christie and Wise, 1960; Churchill-Davidson, 1962).

Stimulation of peripheral nerves for the assessment of muscle relaxation in conditions of clinical narcosis was employed by Volikov (1954), Yamamura and Yamamoto (1958), Weis, Kleinhauss and Hauenschild (1961) and Bark (1962). However, these authors did not draw any conclusions regarding the division of curarization into phases or degrees.

Brown (1955) suggested that relaxation be subdivided into five stages, on the basis of the dynamics of indirect electrical stimulation of muscles and on tendon reflexes. However, his division of these stages, especially of the first three, is highly subjective.

*This paper was read at the All-Union Symposium on "The Use of Relaxants" on January 25, 1963.
The degree of neuromuscular block which should be achieved in thoracic operations is uncertain, as is also the necessity or otherwise of effecting complete block when light narcosis is employed.

With these objectives in view a study was made of the clinical course and character of relaxation in 275 patients, and of the dynamic changes, as shown by electromyography, in forty patients during surgery for acquired heart disease.

METHOD

In all instances ether (3–5 per cent) in oxygen, or nitrous oxide and oxygen (3:1 or 3:1.5), was administered. The depth of anaesthesia was monitored by continuous observation of the electroencephalogram in over half the patients.

Pulmonary ventilation was controlled mechanically or by hand, its adequacy being checked by means of acid base estimation using the Astrup apparatus (Meitina et al., 1962), and oxygen saturation determinations.

Suxamethonium 100 mg was used to facilitate endotracheal intubation and was followed by tubocurarine or gallamine (see table I). In 172 patients a single injection of the long-acting muscle relaxant, in the doses indicated in table I, sufficed for cardiac operations lasting 1½–2 hours.

The electromyogram was recorded using the three-channel Disa-Electronic electromyograph. Rectangular electric stimuli of 1 m.sec duration, with an amplitude of 20–50 V and of varying frequency (0.5, 1, 3, 5, 10, 20, and more per sec) were applied to the ulnar nerve at the elbow by means of a skin bipolar electrode. Concentric needle leads were used to record the electromyogram from the hypothenar muscles. Simultaneously, the movements of the fifth finger were observed.

Visual muscular responses to stimuli of varying frequency were compared with clinical observations of diaphragmatic activity, the nature of spontaneous breathing, muscle weakness and the corneal reflex as well as with the electromyographic pattern.

The following indices were used to evaluate the degree of the neuromuscular block in relation to the dose and duration of action of a relaxant:

(1) Presence or absence of muscular contractility (visually or by electromyography) in response to the stimulus.

(2) Maximal frequency of continuous stimulation which caused no distinct inhibition of the muscular reaction.

(3) The degree of muscular contractility (amplitude of the action potential).

Prior to surgery, many patients suffering from mitral stenosis complained of muscular weakness although the electromyogram failed to demonstrate any signs of impairment of synaptic conductility. Stable muscular contractility was observed in response to the stimulation of the motor nerve within a wide frequency range (from single to tetanic). The action potential amplitude fluctuated individually within the range of from 7.5 to 21 mV (fig. 1).

![Fig. 1](image-url)

Electromyogram before anaesthesia. Rate of nerve stimulation/sec (a) 3; (b) 5; (c) 20.

<table>
<thead>
<tr>
<th>Relaxant</th>
<th>Number of cases</th>
<th>Dosage of relaxant (mg/kg body weight)</th>
<th>Duration in minutes</th>
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<tbody>
<tr>
<td>Gallamine</td>
<td>193</td>
<td>Total: 3.77 ± 0.42, Initial: 3.22 ± 0.27</td>
<td>Narcosis: 139.5 ± 18.2, Operation: 121.0 ± 19.8</td>
</tr>
<tr>
<td>Tubocurarine</td>
<td>82</td>
<td>Total: 0.53 ± 0.07, Initial: 0.47 ± 0.06</td>
<td>Narcosis: 132.4 ± 16.3, Operation: 114.1 ± 14.5</td>
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</table>
Hexobarbitone and thiopentone administered intravenously in doses of 200–650 mg (2.5 per cent solution) failed to affect the neuromuscular conductivity (fig. 2).

Following the intravenous administration of suxamethonium 80–100 mg over 30–40 seconds, fibrillation of the skeletal muscles was noted which appeared on the electromyogram as sporadic outbursts of electrical activity (fig. 3a). Bradycardia was frequently observed on the electrocardiogram and disappeared either spontaneously or after an injection of atropine 1 mg.

In 1 or 2 minutes complete relaxation was achieved (apnoea, widening of the glottis) which made intubation easy, and stimulation of the motor nerve with initial stimuli failed to cause observable contraction of the hand muscles although electromyographic contractions were present (fig. 3b, c, d).

The interval between administrations of suxamethonium and the main relaxant was, as a rule, 7–10 minutes, during which time movements of the diaphragm reappeared and on the electromyogram the amplitudes of action potentials were from 5 to 10 mV (fig. 4). Often either tubocurarine or gallamine was administered before the respiratory muscles had recovered from the effect of suxamethonium, while other muscles were still in the state of complete block as demonstrated by the electromyogram.

The use of suxamethonium at the beginning of narcosis in combination with tubocurarine or gallamine caused no antagonism and was always instrumental in bringing about a smooth development of relaxation. We failed to observe “muscular anarchism” symptoms as described by Smolnikov et al. (1962) after consecutive administration of suxamethonium and Diplacin.*

During that period of time electromyography demonstrated a progressive decrease of the amplitude of the action potentials accompanied by fading of subsequent responses in comparison with the initial one (characteristic of the antidepolarizing block), the rate of stimulation being 3–10 impulses per second. There was also a decrease in amplitude following tetanic stimulation (fig. 5). Well-marked neuromuscular block without signs of antagonism was established in the majority of cases 6–12 minutes after the administration of tubocurarine or gallamine. It was more profound than in patients to whom antidepolarizing relaxants alone were administered: a single stimulus either failed to cause any muscular contraction or

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* Diplacin is a synthetic muscle relaxant available in U.S.S.R. and is claimed to have an antidepolarizing effect. Chemically it is diplatineciummethoxybenzene dichloride.
it was negligible (fig. 6). The actions of tubocurarine and gallamine were more profound and rapid in patients with initial metabolic acidosis. Patients who had had corticosteroids, either pre-operatively or during operation, showed a diminished response, both in degree of neuromuscular block and duration of action. Diaphragmatic contractility either did not disappear or reappeared in 10–20 minutes. The electromyograph demonstrated persistent muscle action potentials in response to repeated stimuli of the frequency of 1–5 and sometimes 10 per second (fig. 7).

This degree of neuromuscular block was not sufficient for intrathoracic operations.

The beginning of the operation was not accompanied by any changes in the condition of the patients: arterial pressure and cardiac rhythm remained stable, the pupil small and the skin dry and pink. Artificial pulmonary ventilation usually induced a respiratory alkalosis (pH 7.40–7.55; Pco₂ 12–28 mm Hg), the degree of which was well controlled by using the Engström ventilator.

The achieved level of relaxation, the course of narcosis being smooth, was maintained at the most crucial moment of the operation when the chest was open and there were manipulations of the lungs, pericardium, large blood vessels, etc.; in 30–60 minutes the nerve-muscle conductivity (stimulus 2, 5 or 10 per sec) was gradually restored (increase of action potential amplitude and muscle response to repeated stimuli), and this coincided with the return of the corneal reflex and first contractions of the diaphragm.

At the final stage of the operation (the suturing of thoracic wound), 90–120 minutes after the administration of the muscle relaxant, natural respiration, inadequate as a rule, was restored (the minute volume ventilation being 3–5 1./min; pH 7.22–7.45; Pco₂ 25–49 mm Hg). Stimulation of the motor nerve at a frequency of 1/sec led only to partial inhibition of the contractility and decrease of action potential amplitudes (fig. 8). After cessation of narcosis the patients opened their eyes and moved. This was followed by a rapid drop in the bio-electrical activity of the hand muscles (fig. 9).
The maintenance of the desired level of pulmonary gas exchange required periodical artificial ventilation of the lungs with an air-oxygen mixture, in spite of the fact that in many patients the minute volume was 5–7 l. Adequate natural respiration was restored about 1 hour after the first diaphragmatic contractions. However, the electromyogram during 1.5–2 hours demonstrated signs of neuromuscular block of an antidepolarizing type (fade away of consecutive action potentials with a frequency of stimulation of 5–10/sec, and post-tetanic facilitation; fig. 10). The only clinical manifestation of residual relaxation was nystagmus and a fixed stare which normally disappeared when there was restoration of neuromuscular conductivity as judged by the electromyogram (repeated stimulation at frequencies of 1–20/sec without noticeable inhibition of action potential amplitude, absence of post-tetanic facilitation). The serial changes in the amplitude of the action potentials are shown in figure 11.

Thus, the clinical course of relaxation from the moment of administration of muscle relaxants up to complete neutralization of the latter’s effect on the neuromuscular junctions can be divided into phases, while the depth of the induced block and the length of its individual stages is conditioned by numerous factors. These include the dose of relaxant, the drugs used in premedication, and the development of metabolic and respiratory changes in the acid-base balance of the patient.

The regularly observed changes in the indirect muscular excitation and clinical manifestations of neuromuscular block made it possible to differentiate between the main stages of the latter (see table II).

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**Fig. 10**
Electromyogram 180 minutes after gallamine 200 mg.
Rate of nerve stimulation 5/sec.

**Fig. 11**
Serial changes in the amplitude of action potentials.
- - - - subsequent potentials after repeated stimulation.
- - - - initial action potential amplitude.
The scale on the axes is arbitrary, being neither linear nor logarithmic.
TABLE II
Periods and stages of relaxation.

<table>
<thead>
<tr>
<th>Periods</th>
<th>Stages</th>
<th>Clinical symptoms</th>
<th>Electromyographic characteristics</th>
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<tr>
<td>1. Development of the block.</td>
<td>Gradual relaxation of the skeletal muscles beginning with the facial and cervical muscles. Decrease of the respiratory minute volume and onset of apnoea.</td>
<td>Progressive fall of potential amplitude. Stimulation of the motor nerve with the frequency of over 1/second causes a distinct decline of the amplitude of action potentials.</td>
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<td></td>
<td>(b) Optimal relaxation.</td>
<td>(b) There is slight muscular contractility to isolated stimulus (0.5–1 mV). Repeated stimulation of slow frequency (2–3/10 sec) causes total inhibition.</td>
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<td></td>
<td>(c) Insufficient relaxation.</td>
<td>(c) Characteristic muscular capacity of maintaining repeated stimulation of the frequency of 3–5/10 sec and later 3–5/sec. Intensification of muscular contractility.</td>
<td></td>
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<tr>
<td>3. Period of restoration of neuromuscular excitation conductivity.</td>
<td>Diaphragmatic respiration. Controlled or assisted respiration is needed for maintenance of adequate gas exchange. Following cessation of narcosis the patient makes voluntary movements; muscular weakness is noted. Slurred speech and nystagmus-like jerking of the eyes in a fixed stare are noted.</td>
<td>Tetanic muscular contractility is either absent or strongly inhibited. Inhibition of potentials is well pronounced after repeated stimulation of the frequency 3–5 and more/sec.</td>
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<tr>
<td></td>
<td>Latent residual relaxation.</td>
<td>Adequate respiration. Slight trembling of the eyeballs in fixed stare is noted.</td>
<td>Inhibition of potential amplitude is preserved in high-frequency stimulation (5–20/sec); post-tetanic facilitation sets in.</td>
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(1) *The period of development of neuromuscular block.*

This is the shortest period and varies with the type of relaxant and the method of use. Suxamethonium has a rapid onset, while the antidepolarizers have a gradual onset over 10–15 minutes. The administration of suxamethonium prior to gallamine or tubocurarine reduces the time of onset of block. Dynamic electromyographic recordings demonstrated that the inhibiting action of muscle relaxants on neuromuscular conductivity varies. The degree of block is maintained for a certain period of time.

(2) *The period of relative stability of the neuromuscular block.*

The length of time of total curarization is defined by the time interval between the onset of apnoea and the reappearance of diaphragmatic activity. However, the degree of neuromuscular block at this time may vary from complete inhibition of synaptic transmission to preservation of muscular response to stimuli given at rates between 1 and 5/sec.

In this connection, three stages of relaxation may be clearly discerned:
(a) **Deep relaxation.** There is no response to indirect excitation. This stage appears not only after administration of single or repeated doses of tubocurarine, but also follows the deepening of narcosis, metabolic acidosis, cardiovascular insufficiency and other states.

(b) **Optimal relaxation.** This is present when the electromyogram demonstrates the persistence of negligible muscular responses (0.5–1 mV) which fade completely after repeated stimulation. Experience shows that the maintenance of curarization at this level provides for the smooth performance of thoracic surgery in conditions of light narcosis. It is not advisable to increase the neuromuscular block in normal surgical operations of 1.5–3 hours duration because it may lead to undesirable prolongation of the block.

(c) **Insufficient relaxation.** This may occur at the beginning of the period of relative stability, due to inadequate dosage or to increased resistance of the patient, as well as at the end of this period. In the first case, neuromuscular conductivity is preserved, the stimuli being 1–5/sec; in the second case the muscle begins to respond to slow stimulation (not more than 1/sec). The development of these signs during surgery indicates the necessity for a further dose of the main muscle relaxant, while a brief deepening of narcosis proves sufficient at the end of the operation.

(3) **The period of restoration of neuromuscular conductivity**

This period is the longest and relates, as a rule, to the end of the operation and the immediate postoperative period (2–4 hours). From a practical point of view it is possible to subdivide it into two stages of manifest and latent residual relaxation. The first stage is seen on the electromyogram as well-pronounced inhibition of muscle action potentials, the stimulation being 3–10/sec; clinically this stage is characterized by inadequate respiration. The persistence of electromyographic signs of block in response to stimulation following the restoration of adequate respiration can be considered as evidence of latent residual relaxation.

It is clear that the correct evaluation of the degree of block makes it possible to control the action of different muscle relaxants and their antidotes. In this way complications in the early postoperative period can be prevented. The simplest and most efficient guide during operation is the assessment of the contractions of the muscles of the hand in response to motor nerve stimulation.

**REFERENCES**


L'ÉVALUATION DU DEGRÉ DE DÉTENTE MUSCULAIRE PENDANT LA RESPIRATION ARTIFICIELLE "CONTROLLÉE".

SOMMAIRE
Les auteurs ont étudié la détente ("relaxation") pré-opératoire chez 275 patients avant des interventions intra-cardiales (en particulier des valvotomies mitrales) sous narcose légère et ventilation respiratoire contrôlée, — L'intubation de suxaméthonium fut suivie de tubocurarine ou de gallamine pour l'opération. D'après les précisions obtenues par stimulation des nerfs moteurs des muscles, l'électromyographie et les renseignements chirurgicaux, et cliniques, les auteurs estiment qu'il y a lieu de subdiviser les processus de détente en plusieurs phases. Une telle subdivision faciliterait le maintien d'un contrôle de la détente pendant l'opération et la période lui succédant immédiatement.

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(3) Catecholamines and their Significance in Anaesthesia (Chairman: Prof. R. Frey, Mainz, Germany)
(4) The Need for and Functions of the Department of Anaesthesiology at the Hospital and at the University (Chairman: Prof. Juan A. Nesi, Caracas, Venezuela)
(5) The Mechanism of Action of Local Anaesthetics (Chairman: Philip R. Bromage, Montreal, Canada)
(6) Clinical use of Halogenated Agents (Chairman: Lucien Morris, Seattle, U.S.A.)
(7) Paediatric Anaesthesia for Correctable Congenital Anomalies (Chairman: Digby Leigh, Los Angeles, U.S.A.)

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   Dr. H. R. Terry jr., Secretary, Mayo Clinic, Rochester, Minnesota, U.S.A.
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