ELECTROMYOGRAPHIC AND MECHANICAL EFFECTS OF
SUXAMETHONIUM AND TUBOCURARINE ON TWITCH, TETANIC
AND POST-TETANIC RESPONSES

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SUMMARY
In an effort to reconcile conflicting reports in the literature concerning suxamethonium and tubocurarine, we studied the effects of these agents on the adductor pollicis mechanical twitch, adductor pollicis brevis compound action potential and abductor digiti quinti compound action potential. It was observed that the magnitude of block of the adductor pollicis differed from that of the abductor digiti quinti. In addition, the magnitude of adductor pollicis block recorded mechanically differed from that recorded electrically. It was further observed that the presence or absence and magnitude of fade and post-tetanic potentiation depended upon the muscle studied, the rate of stimulation, the anaesthetic technique employed, the degree of block and whether electrical or mechanical responses were recorded. Nevertheless, by recording electrical and mechanical effects, it was possible to distinguish clearly the depolarizing block produced by suxamethonium from the desensitizing block produced by this agent as well as from the non-depolarizing block produced by tubocurarine.

The effects of suxamethonium and tubocurarine on neuromuscular transmission in man were once regarded as simple. The block produced by tubocurarine was non-depolarizing and characterized by the presence of: (1) fade; (2) post-tetanic potentiation (facilitation); and (3) antagonism by cholinesterase inhibitors (Churchill-Davidson and Christie, 1959). The block initially produced by suxamethonium was depolarizing and was characterized by the absence of: (1) fade; (2) post-tetanic potentiation; and (3) antagonism by cholinesterase inhibitors (Churchill-Davidson and Christie, 1959). With sufficient dosage and the passage of time the suxamethonium block came to resemble the tubocurarine block and was labelled desensitizing (dual, mixed, phase II non-depolarizing) (Churchill-Davidson, Christie and Wise, 1960; Katz, Wolf and Papper, 1963).

The present status is much more confusing. It has been suggested that after the first small dose of suxamethonium there is fade and post-tetanic potentiation and the block is desensitizing in nature (de Jong and Freund, 1967). On the other hand, it has been suggested that after tubocurarine there is no fade and no post-tetanic potentiation (Heisterkamp, Skovsted and Cohen, 1969). Thus we have a reversal of the original concept.

The present study was undertaken in an attempt to clarify the characteristics of the blockade produced by suxamethonium and tubocurarine. Careful attention was paid to the experimental conditions because it was noted that these differed significantly in the various studies. Major differences include the muscles studied (adductor pollicis brevis or abductor digiti quinti) the recording techniques (mechanical or electromyographic) and the rates of stimulation employed (twitch or tetanic at different frequencies). In the present study electrical and mechanical responses were recorded, both the adductor pollicis and abductor digiti quinti were studied, and the rate of stimulation was varied.

METHODS
Studies were carried out with consent during anaesthesia and operation on patients 21–63 years old, with no known neuromuscular abnormalities. Most of the patients received atropine or hyoscine 0.4–0.6 mg, pentobarbitone 50–100 mg and/or pethidine 50–100 mg for preanaesthetic medication. After an
intravenous infusion was started patients were given pethidine 50-100 mg in divided doses. They were then given either thiopentone 250-500 mg or droperidol 5-7.5 mg. The results in patients who received droperidol did not differ from those who did not. Tracheal intubation, if carried out, was accomplished with the aid of topical application of 4-5 ml of 4% lignocaine solution and/or hypnosis. Anaesthesia was maintained with nitrous oxide, and increments of thiopentone and pethidine. Ventilation was assisted or controlled, as clinically required.

Neuromuscular transmission was studied in the following manner. The ulnar nerve was supramaximally stimulated at the wrist using surface electrodes. The stimulating and electromyographic recording instrument was the TECA 4 electromyographic unit. The stimulator delivered a supramaximal stimulus of 0.1 msec duration every 5 seconds. At appropriate intervals tetanic trains of 20 or 50 Hz were given for 5 seconds. Immediately before or after tetanic stimulation the frequency of stimulation was manually controlled and was applied at a rate of one stimulus every 5-10 seconds. Adduction of the thumb (attributable mainly to the adductor pollicis brevis muscle) was measured with a force displacement transducer (Grass FT10) and recorded on a single channel recorder. A resting tension of 50-150 g was applied to the thumb.

The adductor pollicis electromyogram (thenar e.m.g.) and the abductor digiti quinti electromyogram (hypothenar e.m.g.) were recorded by means of surface electrodes. The TECA 4 allows continuous observation of all the compound muscle action potentials on an oscilloscope and, by pressing a button, production of a written record of the next action potential whilst simultaneously observing it on the oscilloscope. The written record is on ultraviolet light sensitive paper which develops in approximately 5-10 seconds. It is therefore possible to observe the electromyographic results of the experiment continuously and record when desired. It is also possible to operate the TECA 4 manually so that pressing a button both triggers the stimulator and records the response. In this study all of the mechanical twitch responses were recorded and selected electrical responses were recorded. A simple letter and number code was used to correlate electromyogram with mechanical responses.

After a stable level of anaesthesia had been achieved, initial twitch, tetanic and post-tetanic responses were obtained. Then, in one group of patients six or seven 0.5 mg/kg doses of suxamethonium were injected and the mechanical twitch response and the thenar and hypothenar electromyogram observed and, when appropriate, recorded. In 3 patients the mechanical twitch response and thenar electromyogram were recorded, in 3 patients thenar and hypothenar electromyograms were recorded, and in 6 patients mechanical twitch responses and thenar and hypothenar electromyograms were recorded. Tetanic stimulation was applied at 50 Hz in these 12 patients. When mechanical twitch height depression was approximately 75 and 35% the effects of tetanic stimulation were determined. Tetanic stimulation was applied only twice (at less than and at greater than 50% recovery of mechanical twitch response) because recovery from a 0.5 mg/kg dose of suxamethonium is rapid and tetanic stimulation produces changes in the mechanical twitch response which may persist for as long as 11 minutes (see below). In 5 additional patients one 0.5 mg/kg dose of suxamethonium was given and twitch response and thenar and hypothenar electromyograms recorded. The effect of tetanic stimulation at 20 Hz was determined when mechanical twitch height depression was approximately 75 and 35%.

In another group of 6 patients, repeated 0.05 mg/kg doses of tubocurarine were given until mechanical twitch height was depressed approximately 75%. The mechanical twitch response was continuously recorded and thenar and hypothenar electromyograms were recorded at appropriate intervals. Tetanic and post-tetanic responses were determined when mechanical twitch depression was approximately 75 and 35%.

Mechanical twitch effects were calculated by comparing the control twitch height with that recorded after tetanic stimulation or injection of muscle relaxants. Thenar and hypothenar electromyogram effects were calculated by measuring the height of the major peak of the compound action potential and comparing the control response with that obtained after tetanic stimulation or injection of muscle relaxants. Fade of the mechanical response was calculated by comparing the maximum and minimum height during the 5-second period of tetanic stimulation. Fade in the electromyogram was calculated by comparing the maximum and minimum action potential amplitude of the first twenty action potentials during application of tetanus. In preliminary studies it was found that maximum fade invariably occurred during this time. Post-tetanic potentiation was determined by comparing the maximum and minimum
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mechanical or electromyographic response occurring after application of tetanus. The rationale for use of the minimum response after application of tetanus rather than the last response before tetanus has been previously discussed and is particularly important in studies of suxamethonium during which the intensity of the block is changing rapidly (Katz and Ryan, 1969).

A massive amount of data were obtained during these studies. Records were analysed only to answer specific questions concerning the presence or absence of fade, the presence or absence of post-tetanic potentiation and the relationship between the mechanical twitch and the thenar and hypothenar electromyographic responses.

RESULTS

Tetanic and Post-tetanic Responses Prior to Relaxants

In the mechanical records the responses to tetanic stimulation (50 Hz) were well sustained throughout the 5-second period of stimulation (i.e. "mechanical" fade was not seen). In 18 patients studied the thenar electromyogram showed evidence of fade in 6 but facilitation in 10, whilst in 15 of these patients fade was observed in the hypothenar electromyogram in 4 and facilitation in 11 (table I). It was possible in a given patient to observe electrical evidence of fade in one muscle and facilitation in another (fig. 1, table I).

Post-tetanic potentiation (PTP) was seen in the mechanical response in all patients and averaged 37% (table I); this lasted 2–11 min. It was not reflected in the electromyograms of the thenar or hypothenar muscles (table I, fig. 1). There was either no change in action potential amplitude or only a slight increase (maximum of 7%).

Suxamethonium (First Dose)

Differential effects on mechanical and electrical responses.

The intravenous injection of suxamethonium decreased and abolished mechanical and electrical responses in all patients. During the development of the block the thenar electromyogram was depressed to a greater extent than the mechanical twitch response in 7 of 9 patients. In the remaining 2 patients this was true except when the mechanical twitch height was depressed 80% or more, at which time the thenar electrical response was similarly depressed. Figure 2A shows a comparison of the degree of block in the mechanical response with the

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<thead>
<tr>
<th>Table I. Tetanic and post-tetanic responses before administration of muscle relaxants in 18 patients.</th>
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<tr>
<td>Per cent tetanic fade (−) or potentiation (+)</td>
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<tr>
<td>Mechanical</td>
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Results in 18 patients listed and mean±SE calculated. *indicates not recorded.

Mechanical = Mechanical twitch response.
Thenar e.m.g. = Electromyogram from adductor pollicis brevis muscle.
Hypothenar e.m.g. = Electromyogram from abduction digiti quinti muscle.
**CONTROL TETANUS**

![Diagram of control tetanus responses](image)

**FIG. 1.** Response to tetanic stimulation prior to relaxants. Panel A: mechanical responses. Calibration is for single twitches. Tetanic stimulation (50 Hz) at T carried out at 1/5 the gain. Note post-tetanic potentiation in mechanical record. Panels, B, C, D: electromyographic recordings; adductor pollicis (upper tracing) and abductor digitii quinti (lower tracing). Note absence of electromyographic evidence of post-tetanic potentiation comparing the first and twelfth post-tetanic response (PT₁ and PT₁₂). Also note in panel B that during tetanic stimulation there is fade in the record from the adductor pollicis but facilitation in that from the abductor digitii quinti.

![Graph of mechanical twitch block](image)

**FIG. 2.** Comparison of effect of succinylcholine (SDC) on mechanical response and thenar electromyogram block (panel A) and hypothenar and thenar electromyogram block (panel B). Note in panel A the greater magnitude of thenar electromyogram block as compared with mechanical block while in panel B approximately equal numbers of points lie on each side of identity line.

![Graph of SDC 0.5 mg/kg](image)

**FIG. 3.** Effects of succinylcholine (SDC) on mechanical and electrical recordings. Upper panel: mechanical effects. Note facilitation prior to onset of block. Tetanus (50 Hz) at T₁ (first tetanic stimulation) is at same gain as twitch but T₂ (second tetanic stimulation) is at 1/5 indicated gain. Note recovery to greater than control levels. Lower two panels are electromyograms (same convention as fig. 1). Note that although mechanical twitch responses B and C in upper panel are greater than control, the electromyogram responses are depressed. In addition, while mechanical response G is greater than control, electromyogram responses H are less than control. When electromyogram responses H are back to control, mechanical response H is still greater than control. Also note that on electromyogram response T₁ there is less fade on the abductor digitii quinti record than on the adductor pollicis record. The same is true for electromyogram response T₂. Although there is substantial electromyogram fade on T₂, there is little fade in the mechanical response.
degree in the thenar electromyogram. In all 9 patients the mechanical twitch response recovered faster than the thenar electrical response. While the thenar electrical response returned to the control level in all patients, in 8 of the 9 patients the mechanical twitch response returned to a level greater than control (fig. 3). This elevated mechanical twitch recovery level was 12–40% (average 25%) greater than control and persisted as long as 20 minutes in the 8 patients. It was therefore possible to have a mechanical response equal to or greater than control at a time when the thenar electrical response was less than control. It was also observed that the increased mechanical twitch response seen before the onset of block was associated with a diminished thenar and hypothenar electromyogram response (fig. 3).

The sensitivity of the electrical responses of the thenar and hypothenar muscles to suxamethonium also varied (fig. 2B). During the development of the block the thenar response was depressed more than the hypothenar in 3 patients, the reverse was seen in 4 patients, and in 2 patients the responses were similar. During recovery the thenar response recovered more slowly than the hypothenar in 3 patients, the reverse occurred in 5 patients, and recovery was similar in 1 patient.

The results reported in this section can be summarized by stating that the assessment of the degree of block and duration of action of suxamethonium differs markedly depending upon whether one monitors the mechanical twitch response, the thenar electromyogram response or the hypothenar electromyogram response.

Tetanic responses during recovery.

Fade of the mechanical and electrical responses during tetanic stimulation at 50 Hz was studied at two levels of mechanical block (73 and 35%; table IIa) in the 6 patients in whom the mechanical twitch response, and the thenar and hypothenar electromyogram responses were recorded. It can be seen from the data in table IIa and figure 3 that the degree of fade varied with the muscle being studied, how fade was assessed (electrically or mechanically) and the degree of block at which it was studied. It can be stated in general that: (1) the smaller the extent of block the smaller the degree of fade; (2) in the thenar muscle fade in the electromyogram is usually greater than in the mechanical record; and (3) fade is usually greater in the thenar than the hypothenar muscles, as seen in the electromyogram.

In 5 patients in whom tetanic responses to 20 Hz were studied, lesser degrees of fade were observed than in the above patients studied at 50 Hz (table IIc, fig. 4).

Post-tetanic responses during recovery.

The presence or absence of potentiation after stimulation at 50 Hz was also studied at a depression of the mechanical response of 73% and 35% (table IIa). There was no evidence of facilitation in the mechanical record in any patients at a smaller degree of block. At the greater degree of block there was no evidence of post-tetanic potentiation in 4 patients whilst in 2 patients potentiation of 5 and 16% was observed in the mechanical record. This was less than the control value seen before relaxant injection. In electrical recordings from the thenar and hypothenar muscles, post-tetanic potentiation was not observed at either level of block. In the recordings from 5 patients studied after application of tetanus at 20 Hz there was no evidence of facilitation in the electrical or mechanical respon-

<table>
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<th>TABLE II. Tetanic and post-tetanic responses after suxamethonium.</th>
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<tbody>
<tr>
<td><strong>Per cent mechanical block</strong></td>
</tr>
<tr>
<td>Mechanical</td>
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<tr>
<td>(A) Suxamethonium (1st dose)</td>
</tr>
<tr>
<td>Tetanic frequency 50 Hz</td>
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<tr>
<td>6 patients</td>
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<tr>
<td>(B) Suxamethonium (6th dose)</td>
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<tr>
<td>Tetanic frequency 50 Hz</td>
</tr>
<tr>
<td>5 patients</td>
</tr>
<tr>
<td>(C) Suxamethonium (1st dose)</td>
</tr>
<tr>
<td>Tetanic frequency 20 Hz</td>
</tr>
<tr>
<td>5 patients</td>
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</tbody>
</table>

Results are mean ± SE
FIG. 4. Responses to tetanic stimulation at 20 Hz during suxamethonium (SDC) recovery. Panel A: mechanical response. Tetanic stimulation at T₁ is at same gain as twitch responses but T₂ is at 1/5 indicated gain. Note that there is only slight fade at T₁ and even less at T₂ at this stimulation frequency. Panel B: electromyogram responses during T₁. Note fade on adductor pollicis trace (upper) but not on abductor digitus quinti trace (lower).

Suxamethonium (Sixth Dose) Changes in Fade and Facilitation (50 Hz)

There were changes in fade and facilitation as repeated doses of suxamethonium were given to 5 of the 6 patients in whom mechanical twitch responses and thenar and hypothenar electromyograms were recorded. Comparing the effects of the sixth dose of suxamethonium with those of the first dose (table IIa, b, fig. 5) the degree of fade was greater after the sixth dose. This observation was consistent in all three records. An even more dramatic change was the presence of post-tetanic facilitation in the electromyograms in all 5 patients after the sixth dose when none had been observed after the first dose (table IIa, b, fig. 5). In addition facilitation was now seen in the recordings of the mechanical response in all 5 patients.

Edrophonium

In 4 patients a seventh dose of suxamethonium was given and when the mechanical response showed a block of approximately 69% edrophonium 0.15 mg/kg was injected. In all patients the rate of recovery of mechanical twitch height and of thenar and hypothenar electromyogram responses was accelerated. Repetitive discharge was not observed.

Tubocurarine.

Differential effects on mechanical twitch and electrical responses.

The intravenous injection of tubocurarine decreased the mechanical and electrical responses to a different degree (fig. 6). Figure 7A shows the relationship between the mechanical twitch height depression and the thenar electromyogram response, and figure 7B shows a comparison of the thenar and the hypothenar electromyograms. The mechanical twitch response was depressed more than the thenar electromyogram response in 4 of 6 patients. The
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hypothenar electromyogram response was depressed less than the thenar or mechanical twitch response in 5 of 6 patients. During recovery the hypothenar electromyogram recovered most rapidly, the thenar electromyogram next and the mechanical twitch height last. Thus, if one compared the electrical response of the thenar or hypothenar muscles with the mechanical twitch response during the development of the block and during recovery, at the same level of mechanical twitch depression the thenar and hypothenar electromyogram response to stimulation would be greater during recovery than during development of the block.

Tetanic and post-tetanic responses.

The presence or absence of fade and facilitation were determined at a mechanical twitch depression of 74 and 36% (table III, fig. 6). Evidence of fade was observed in the mechanical response records in 5 of 6 patients at the greater degree of block and in 3 of 5 at the lesser block. In the thenar and hypothenar electromyograms fade was seen at both levels of block in all patients.

Post-tetanic potentiation exceeding the control response was observed on the thenar and hypothenar electromyograms in all patients at both levels of block. Potentiation greater than control was observed on the mechanical twitch response at the greater level of block in all 6 patients and at the lesser level in 3 of 6 patients.

Rest potentiation.

It was observed that if stimulation was discontinued for 1 minute, then, upon resuming stimulation, the initial mechanical twitch response was greater than the last response before the rest period. As stimulation was continued this rest potentiation disappeared and the mechanical twitch response height returned to the pre-rest level. This rest potentiation was also observed in the thenar and hypothenar electromyograms.

DISCUSSION

The present study was stimulated in large measure by the papers of Heisterkamp, Skovsted and Cohen (1969) and de Jong and Freund (1967). The former group stated that with a 65 % block of the mechanical twitch response produced by tubocurarine, 63% of patients did not show evidence of fade during tetanic stimulation at 30 Hz and that even with a degree of block greater than 90% fade was not demonstrable in the majority of patients. In addition they reported that post-tetanic facilitation was not seen with tubocurarine. The latter group reported that the initial block produced by small doses of suxamethonium was characterized by fade and post-tetanic potentia-

<table>
<thead>
<tr>
<th>Per cent mechanical block</th>
<th>Mechanical</th>
<th>Thenar e.m.g.</th>
<th>Hypothenar e.m.g.</th>
<th>Per cent mechanical block</th>
<th>Mechanical</th>
<th>Thenar e.m.g.</th>
<th>Hypothenar e.m.g.</th>
</tr>
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<tbody>
<tr>
<td>Per cent tetanic fade (-)</td>
<td></td>
<td></td>
<td></td>
<td>Per cent post-tetanic potentiation (+)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>74±3.0 (6 patients)</td>
<td>-62±13</td>
<td>-76±12</td>
<td>-64±12</td>
<td>+215±3.0</td>
<td>+188±39</td>
<td>+91±18</td>
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<tr>
<td>36±4.3 (5 patients)</td>
<td>-30±13</td>
<td>-57±11</td>
<td>-53±8.4</td>
<td>+51±6.4</td>
<td>+34±6.0</td>
<td>+31±7.3</td>
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Tetanic stimulation 50 Hz Results are mean ± SE

Fig. 6. Effects of tubocurarine (dTC) on mechanical and electrical recordings. Upper panel: mechanical responses. Tetanic stimulation (50 Hz) at T at same gain as twitch. Note depression produced by tubocurarine, fade and post-tetanic potentiation. Lower panel: electrical response. Note that the percent block of both muscles is less than the block shown in the mechanical record from the adductor pollicis.
tion. They stated that a phase I (depolarizing) block, characterized by well sustained tetanus and absence of potentiation, was never seen, even with doses of suxamethonium as small as 10 mg. They concluded that "phase I, phase II and curare-type block cannot be differentiated clinically on the basis of muscle responses to nerve stimulation." The results and conclusions of these studies are contrary to accepted views, and if confirmed would require a major reorganization in our thinking of neuromuscular blocking agents.

de Jong and Freund (1967) also concluded that there was a close association between electromyographic and tension recordings in the unanaesthetized subject as well as during neuromuscular block in anaesthetized patients. They felt that the electromyogram and muscle tension recordings could be used interchangeably. In our previous studies of muscles of the hand we reported that although muscle relaxants could have a similar effect on mechanical and electrical events under some circumstances, under other circumstances there were marked differences in electrical and mechanical events (Katz, 1965). In studies of ventilation we also reported that electrical and mechanical activity might differ and reviewed the substantial literature on this subject (Katz, Fink and Ngai, 1962).

In designing the present study we reviewed the previous studies in an attempt to find possible explanations for the difference in the results obtained. The most striking differences were in the anaesthetic techniques used, the monitoring methods, the stimulation frequencies, the muscles monitored, the levels of block at which fade and post-tetanic potentiation were studied, and the way in which data were analysed. We believe that these differences can explain many but not all of the reported differences.

Control responses to tetanus.

Before considering the effects of suxamethonium and tubocurarine on fade and facilitation, the control responses must be discussed. Prior to the injection of any relaxant, the mechanical response to tetanus was well sustained and there was facilitation in the mechanical response averaging 37%. On electromyographic recording, thenar and hypothenar action potential height was usually well sustained or increased during tetanus. Post-tetanic potentiations were not seen on the electromyogram recording although it was observed on mechanical recordings. These results are similar to those found by others (Botelho and Cander, 1953; Hughes, 1958; Özdemir and Young, 1971) with the following exceptions: Epstein and Epstein (1973) studying 8 patients found during tetanic stimulation a decrease in thenar action potential height of 4, 7, 20, 24 and 30%. de Jong and Freund (1967) found evidence of post-tetanic potentiation in the electromyograms. Since both of these groups made their control measurements during halothane anaesthesia it is possible that this may be a factor responsible for their results.

Suxamethonium and fade (first dose).

The effect of the initial dose of suxamethonium on fade as seen in the mechanical record was found in this study to depend upon the level of block and the frequency of stimulation. At a mechanical block greater than 50% and on stimulation at 50 Hz there was marked fade. With a block less than 50% and stimulation at 20 Hz there was little or no fade. Ali, Utting and Gray (1970) showed that halothane anaesthesia affected the development of fade in the mechanical response. When stimulating at 2 Hz for 2 seconds, they found no evidence of fade after suxamethonium administration in patients anaesthetized with nitrous oxide. However, during halothane anaesthesia, fade was observed. Thus the presence of fade in the twitch response reported by de Jong and Freund (1967) can be explained in terms of the degree of block at which tetanic stimulation was applied, the frequency of tetanus and their use of halothane.

We also found that the level of block and the frequency of stimulation were important in the development of fade in the electromyogram. Another critical factor, however, was the particular muscle studied, electrical evidence of fade being much less apparent in the hypothenar than the thenar electromyogram. These observations on fade as seen in the electromyogram suggest that the differences in results between the studies of de Jong and Freund (1967) and those of Churchill-Davidson and Christie (1959) can be explained by the fact that the latter group studied the electromyogram from the hypothenar muscles rather than the thenar muscles and used a lower rate of stimulation.

Suxamethonium and post-tetanic responses (first dose).

Post-tetanic potentiation was not seen in the mechanical or electrical records during recovery from the first dose of suxamethonium. Similar results were reported by Katz, Wolf and Papper (1963), and Crul and associates (1966) in studies of the mechani-
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Cal response and Churchill-Davidson and Christie (1959) in electromyographic studies. Although we also pointed out (Katz and Ryan, 1969) that the potentiation seen in the mechanical record following the first dose of suxamethonium reported by de Jong and Freund (1967) was an artifact attributable to the method of measuring, we are unable to explain their findings of potentiation in the electromyogram unless halothane anaesthesia facilitates the development of potentiation as it does fade (see above).

Repeated doses of suxamethonium.

Following repeated doses of suxamethonium we observed fade in the mechanical and electrical recordings regardless of the level of block. Mechanical and electrical evidence of post-tetanic potentiation was also observed following repeated doses. This change in pattern from a depolarizing to desensitizing block has been described by many workers and is widely accepted (Churchill-Davidson, Christie and Wise, 1960; Katz, Wolf and Papper, 1963; Crul et al., 1966). When the block was desensitizing in nature it could be antagonized by edrophonium. The increase in twitch height following edrophonium was associated with an increase in action potential height and was not due to repetitive discharge induced by the cholinesterase inhibitor.

Tubocurarine.

The block produced by tubocurarine in the present study was characterized by the appearance of fade in the electrical recordings in response to tetanic stimulation in all cases and at both levels of block studied. Fade on tetanic stimulation was seen in 5 of 6 patients in the mechanical record at the greater degree of block and in 3 of 5 patients at the lesser degree of block. We previously reported that occasionally mechanical evidence of fade did not occur with tubocurarine (Katz, 1965), a response that Epstein and Epstein (1973) observed in 2 of 8 patients. We are unable to explain why Heisterkamp, Skovsted and Cohen (1969) did not find mechanical fade on tetanic stimulation in the majority of their patients while we and others have.

Post-tetanic potentiation was observed in both mechanical and electrical recordings during a partial tubocurarine block. Although potentiation was observed in the electromyogram at all levels of block studied, potentiation greater than control was consistently observed in the mechanical record only at the greater levels of block. It should be remembered that before the injection of relaxant, potentiation was not observed in the electromyogram but potentiation of 37% was noted in the mechanical response record. The failure of Heisterkamp, Skovsted and

Fig. 7. Comparison of effect of tubocurarine (dTc) on mechanical twitch response and compound action potentials from the thenar (panel A) and hypothenar and thenar muscles (panel B). Note in panel A that, in general, block of the mechanical response is greater than that of the thenar electromyogram response. In panel B, the compound action potentials obtained from the thenar muscles are depressed more than those from the hypothenar muscles.
Cohen (1969) to observe potentiation in the mechanical record during a partial tubocurarine block is explained by their method of data analysis, which involved measuring absolute rather than per cent changes in twitch height. The deficiencies of this type of analysis have been pointed out by Epstein and Epstein (1973). Although we agree with Epstein and Epstein that percentage rather than absolute changes should be used, even calculating post-tetanic potentiation on an absolute basis, it was observed to be greater than control at the larger block in 4 of 6 patients in the recordings of the mechanical twitch response.

Separation of mechanical and electrical events.

We have shown that the presence or absence of fade and facilitation in the control state or after suxamethonium and tubocurarine may depend upon whether electrical or mechanical recordings of evoked responses are studied. An important related finding of the present study is the further dissociation of electrical and mechanical events, in terms of degree of block produced by these muscle relaxants. The mechanical twitch response was usually less sensitive to suxamethonium than was the thenar or hypothenar electromyogram response. This was not true for tubocurarine; instead the mechanical twitch response was usually more sensitive than the thenar or hypothenar electromyogram. Thus, if one were assessing recovery from suxamethonium by study of the mechanical twitch response, then upon return of twitch tension to control values, a substantial block could still be present as judged by the electromyogram. On the other hand, if one were assessing recovery from tubocurarine by study of the electromyogram, then upon return of the response to control levels there could still be substantial muscle weakness, particularly if reliance were placed on electromyograms of the hypothenar muscles. At tetanic rates of stimulation recovery of the mechanical response preceded recovery of the electrical with both suxamethonium and tubocurarine, in that it was possible to have mechanical evidence of well sustained tetanus with both agents at a time when the electrical response to tetanus was poorly sustained.

Further discrepancies between electrical and mechanical activity were noted. With suxamethonium, at a time when facilitation of the twitch response was seen before the onset of block, electrical activity was depressed. Upon recovery from suxamethonium, the mechanical twitch response returned to a level greater than control but action potential height was never greater than control. It was therefore possible to have a stage of recovery at which the mechanical twitch response height was greater than control but the electrical twitch response less than control. This increase in twitch height in the absence of an increase in action potential height seen with suxamethonium as well as before relaxants probably represents a contractile effect on the muscle.

The results of this study suggest that the block produced by suxamethonium is initially predominantly depolarizing in nature but, with sufficient time and dosage, changes to predominantly desensitizing, whilst the block produced by tubocurarine is non-depolarizing in nature. It is also clear that these types of block can be differentiated clinically by determining the muscle response (electrical and mechanical) to nerve stimulation. The discrepancies in electrical and mechanical results observed suggest that where possible both electrical and mechanical responses to nerve stimulation should be studied. If only one of these can be studied the choice will depend upon the nature of the information desired.

REFERENCES


EFFECTS OF ACUTE HYPERCARBIA ON BODY OXYGEN STORES


**EFFETS ELECTROMYOGRAPHIQUES ET MECANIQUES DE SUXAMETHONIUM ET TUBOCURARINE SUR LES REACTIONS DE CONTRACTION, TETANIQUES ET POST-TETANIQUES**

**SOMMAIRE**

Pour essayer de reconcilier les rapports contradictoires de la litterature au sujet du suxamethonium et de la tubocurarine, nous avons etudie les effets de ces agents sur la contraction mecanique du muscle adducteur du pouce, sur le potentiel d'action compose de l'abducteur du cinquieme doigt. On observe que l'importance du block de l'adductor pollicis differa de celui de l'abductor digiti quinti. L'importance du block de l'adductor pollicis enregistre mecaniquement differa en outre du block enregistre electrique. On nota encore que la presence ou absence et l'importance d'inhibition et potentiation post-tetanique dependent du muscle etudie, du taux de stimulation, de la technique anesthesique utilisee, du degré du block et du fait d'enregistrer des reactions mecaniques ou electriques. Mais il etait possible, enregistrant des effets mecaniques et electriques, de distinguer nettement le block depolarisant produit par suxamethonium et le block desensibilisant produit par cet agent, ainsi que du block non-depolarisant cause par tubocurarine.

**ELEKTROMYOGRAPHISCHE UND MECHANISCHE WIRKUNGEN VON SUXAMETHONIUM UND TUBOCURARIN AUF ZUCKUNGEN, TETANISCHE UND POST-TETANISCHE REAKTIONEN**

**ZUSAMMENFASSUNG**