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The Relationship of Evoked Electromyographic and Mechanical Responses following Atracurium in Humans

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Despite widespread acceptance of the principle that monitoring of neuromuscular function during anesthesia is desirable, certain practical difficulties exist. For example, subjective evaluation of mechanical twitch height and fade is often highly inaccurate. Experienced observers frequently are unable to detect fade on train-of-four (TOF) stimulation, even when this ratio is as low as 0.40.[1] Clearly there is a need for a neuromuscular transmission monitor (NMTM) that can quantitate twitch depression from control (T1/Tc) and train of four T4/T1) fade. To be useful to the clinician, however, such a monitor must meet several criteria. A NMTM designed for routine use must be noninvasive, require minimal set up time and attention, allow remote monitoring when access to the site of stimulation is inaccessible, and display T1/Tc and T4/T1 depression in an easily readable or digital format, with trending capability a useful adjunct. All of the above should be available at a nonprohibitive cost. Viby-Mogensen,[2] Ali and Savarese,[3] and Stanec and Stanec[4] all have outlined different approaches to the measurement of evoked mechanical response (mechanomyogram or MMG). Unfortunately, each of the devices described fail to meet the above requirements in at least one area, and only the latter unit is currently available in North America.

The recent commercial introduction of electromyographic (EMG) NMTM units designed for use by the anesthesiologist[5,6] is of interest, since in theory they should be capable of fulfilling all of the above criteria. Although several studies comparing evoked EMG and MMG responses to indirect stimulation have been published,[7–10] none actually correlate them during nondepolarizing neuromuscular blockade. Since preliminary work in our department indicated that the MMG frequently showed significantly more paralysis than was suggested by a simultaneously recorded EMG, we decided to study the correlation between these two responses.

METHODS

Sixteen patients undergoing elective surgical procedures, for which the administration of a muscle relaxant was indicated by the nature of the proposed surgery, were included in the study. The protocol was approved by our hospital's Human Subjects Review Committee. Anesthesia was induced with thiamyl sodium and maintained with nitrous oxide and halothane (0.5–1.0% inspired).

Evoked isometric twitch tension of the adductor pollicis muscle to ulnar nerve stimulation was measured with a Grass FT-10® linear force transducer and recorded. Preload on each patient's thumb was adjusted to approximately 200 g. The evoked integrated compound action potential of the hypothenar muscles of the same hand was simultaneously recorded with the use of a Datex NMT221® Neuromuscular Transmission Monitor. Supra maximal nerve stimulation was achieved using the nerve stimulator incorporated into the Datex® unit (pulse width 100 μs, constant current, 0–70 mA range). Stimulating and recording electrodes were 3M infant Red Dot® electrodes.

After anesthesia was induced and before any muscle relaxants were administered, control EMG and MMG T4/T1 responses were recorded. When both variables were stable for at least 5 min, the study commenced. Atracurium, 0.3–0.4 mg/kg, was given iv. When twitch depression was maximal, the patient's trachea was intubated. Additional doses of atracurium were given as needed to maintain good clinical relaxation and operating conditions. Incremental doses were not administered unless the MMG train-of-four count was three or more. TOF stimulation was given every 20 s for the duration of the case. Single twitch depression (height of first twitch in a train/control twitch) (T1/Tc) and TOF fade ratio (T4/T1) were continuously recorded by the Datex® unit (EMG). Simultaneous MMG determinations were made and recorded whenever the EMG values for T1/Tc or T4/T1 ratio changed by more than 0.03–0.05. An average of 30–40 determinations were generated. At the end of surgery, any residual paralysis was reversed with edrophonium to an MMG T4/T1 ratio of at least

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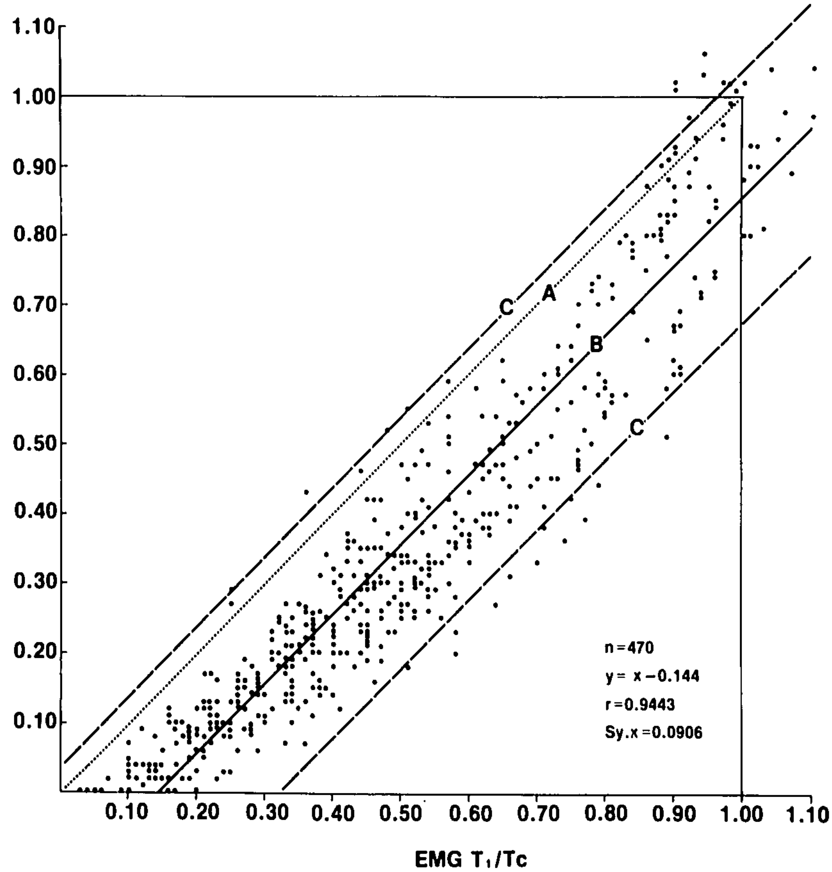

FIG. 1. Comparison of mechanical and EMG T1/Tc ratios. A = line of identity. B = line of regression. C = 95% confidence limits for prediction of individual MMG values.

0.70. Simultaneous responses were examined in pairs by linear regression (least squares) analysis. Only individuals in whom both the MMG and EMG T1/Tc ratio returned to 1.0 ± 0.1 were included in the results (n = 14).

RESULTS

The 14 individuals studied generated 470 data points for T1/Tc analysis and 318 data points for T4/T1 analysis. As can be seen from figures 1 and 2, the simultaneously evoked EMG and MMG do not give identical information. The mechanical response to both single twitch and TOF stimulation is more easily abolished by atracurium than the evoked EMG. The regression line for T1/Tc (fig. 1) is parallel to the line of identity but shows an absolute offset of about 15%. Since the standard error of the estimate of the MMG is ±0.09, the 95% confidence limits for the estimate of any given MMG value when the EMG is known is approximately ±0.18. For example, when the EMG T1/Tc ratio is 0.50, the predicted MMG value is 0.35, with a range of 0.17–0.53. When the EMG T1/Tc is 0.15, the MMG is essentially flat.

The equation for the line of regression for T4/T1 (fig. 2) is MMG = 0.87 × EMG − 0.053. The regression line for T4/T1, however, tends to give a false impression of the relationship between the EMG and MMG TOF count. Once a fourth MMG twitch was visible, the relationship is as pictured in figure 2. As can be seen from table 1, however, at EMG T1/Tc ratios of 0.25, as a rule, only one or two MMG responses are visible following TOF stimulation. Even at EMG T1/Tc values of 0.40–0.45, the fourth MMG twitch is frequently not measurable. Therefore, despite the line of regression cited above, EMG T1/Tc values as high as 0.50 may coexist with MMG TOF counts of less than four.

DISCUSSION

While the evoked MMG and EMG responses to indirect muscle stimulation generally trend in the same direction, they do not give identical information. Katz[8] and Epstein and Epstein[9] have shown that following the administration of *d*-tubocurarine that mean tension was depressed to a greater extent than the EMG response. Neither author documented this discrepancy in any detail, and TOF stimulation was not employed by either investigator. Until quite recently, these data were of theoretic interest only since there were no EMG monitors available intended primarily for routine clinical use. The commercial introduction of anesthesia-oriented

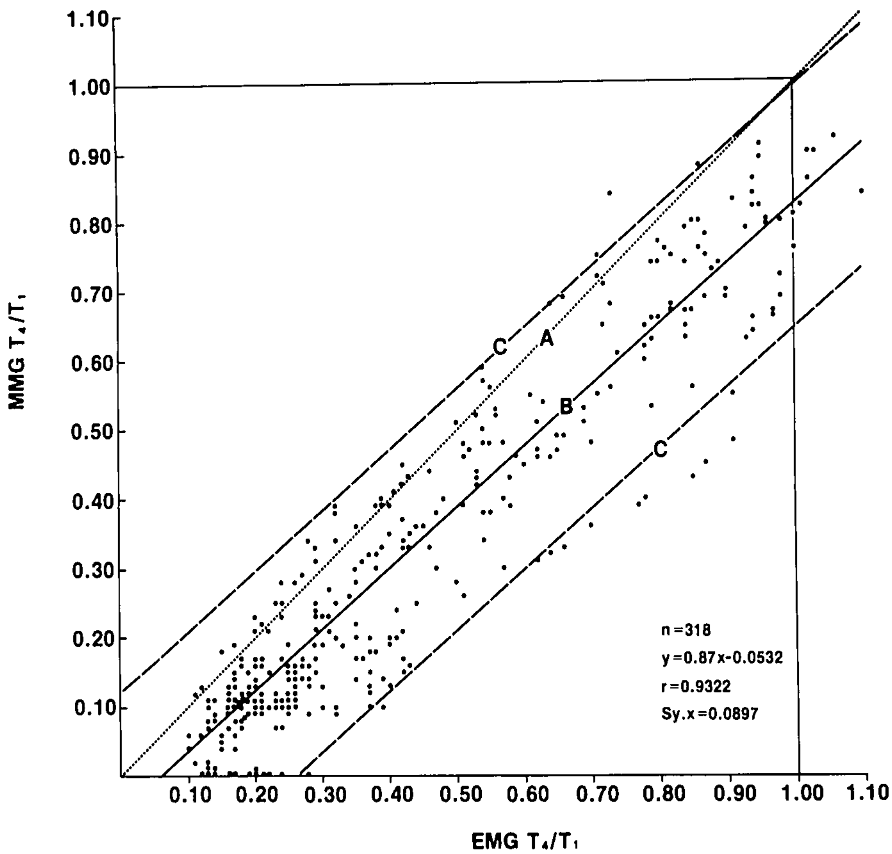

FIG. 2. Comparison of mechanical and EMG T4/T1 ratios. A = line of identity. B = line of regression. C = 95% confidence limits for prediction of individual MMG values.

EMG units, however, raises certain questions. What level of T1/Tc or T4/T1 ratio correlates with adequate clinical relaxation? Does an EMG T4/T1 ratio of 0.70 indicate adequate reversal? While the results of this study do not fully answer these questions, certain observations seem pertinent.

Although the 15% offset found for the regression line relating EMG T1/Tc to MMG T1/Tc might appear to be a small difference, it can have a significant effect on the correlation between the EMG and MMG TOF count. For example, assume an EMG T1/Tc value of 0.45 with a simultaneously recorded T4/T1 ratio of 0.20. It follows that the fourth EMG response is 9% of control. Since the line of regression for T1/Tc is MMG = EMG − 0.15, then the predicted MMG values for T1/Tc and T4/T1 are 0.30 and −0.06, respectively. In other words, the MMG TOF count is less than four. This is exactly the situation that we often encountered (table 1). Our results also agree with what one would predict from the work of Lee.[11] He found that the reappearance of the second mechanical twitch occurs at a MMG T1/Tc ratio 0.10–0.20, and the fourth is seen when the T1/Tc value is >0.25. These would correspond to EMG T1/Tc ratios of 0.25–0.35 and >0.40, respectively, confirming the results in table 1. Thus, when using nondepolarizing muscle relaxants, the EMG T1/Tc ratio need not be depressed much below 0.25 to produce adequate surgical relaxation, and levels as high as 0.40–0.45 may often be quite satisfactory, especially when combined with MAC levels of potent inhaled anesthetics. Since EMG T1/Tc values of <0.1 produce in effect complete MMG suppression, this level of paralysis is probably unnecessarily deep.

TABLE 1. Mean EMG Values for T1/Tc when MMG Second and Fourth Evoked Response Were First Clearly Measurable

	MMG Train-of-four Count	
	2	4
Mean EMG T1/Tc Ratio	0.28 (n = 35)	0.43 (n = 33)
SD (n − 1)	±0.06	±0.09
SE (mean)	±0.011	±0.015

Twitch height of >1.0 mm when Tc was >40.0 mm.

While we found the EMG T1/Tc ratio to be of primary importance in regulating depth of paralysis during a surgical procedure, the T4/T1 value was of greater interest when assessing the degree of reversal of neuromuscular blockade. This is true for several reasons. First, T1/Tc can approach control values at a time when T4/T1 values are still far below 0.6–0.7, the value accepted to represent full clinical recovery.[12]

Second, the EMG baseline may drift with time and return of T1/Tc to control values does not always occur. The two individuals that we excluded from this study had recovery of the EMG T1/Tc ratio to only 0.85 at a time when MMG T1/Tc was >0.95 and both EMG and MMG T4/T1 ratios exceeded 0.70. We also believe that EMG T4/T1 values of only 0.70 following reversal should be viewed with suspicion. At an EMG T4/T1 ratio of 0.70, the predicted MMG value is only 0.55, and we have encountered several individuals where measured MMG T4/T1 ratios were in the range of 0.30–0.40, despite EMG values of 0.70–0.80. In contrast, at EMG T4/T1 values > 0.90, the MMG ratio is predictably above 0.60.

The data generated by the indirectly evoked EMG must be used with some understanding of its limitations as a predictor of mechanical response. In brief, we believe that adequate surgical relaxation is obtained with EMG T1/Tc ratios of between 0.20 and 0.40 and that an attempt should be made to obtain EMG T4/T1 values > 0.90 during reversal of nondepolarizing blockade. With these caveats in mind, we found the integrated EMG to be a useful and convenient clinical tool. Set-up time takes no longer than applying a five-lead electrocardiogram, and once the unit is calibrated, it requires little or no further attention. The ability to quantitate slight to moderate T4/T1 fade allows the clinician for the first time to accurately titrate the use of reversal agents or, occasionally, omit them entirely with a reasonable sense of security. Another benefit of the ability to measure T4/T1 fade is that there is no longer any real need for the application of tetanic stimuli. If tetanic trains are avoided, posttetanic conditioning of subsequent responses are no longer a problem. Finally, small degrees of residual paresis can be looked for in the awake patient without causing undue discomfort.

The regression equations that we generated clearly do not apply to succinylcholine. Katz,[8] in comparing evoked electrical and mechanical events, demonstrated that during recovery from a depolarizing neuromuscular blockade that mechanical twitch response was less sensitive than the EMG. In fact, the MMG may return to levels greater than control at a time when the EMG is still depressed. This work has been confirmed by Shanks and Jarvis[9] and Donati and Bevan.[10]

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