

Acceleromyography improves detection of residual neuromuscular blockade in children

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Purpose: To determine whether detection of residual blockade is improved by using the accelerograph. A secondary objective was to compare acceleromyographic measurements with those obtained by electromyography.

Methods: In a prospective, randomized, double-blind investigation, 22 anaesthetized children were studied during recovery from neuromuscular blockade following $0.1 \text{ mg} \cdot \text{kg}^{-1}$ vecuronium iv. Assessments of depth of block began 10 min after injection and were repeated at one minute intervals using electromyography (Datex, Relaxograph) in one hand, and acceleromyography (Biometer, Tofguard) in the other, to measure responses of the adductor pollicis to train-of-four (TOF) stimulation of the ulnar nerve. Monitoring was stopped when no fade was visible and TOF ratio ≥ 0.7 . The electromyographic (EMG) and acceleromyographic (AMG) data were compared with corresponding observations of the number of twitches and TOF fade in the visible responses of the thumb, made by the attending anaesthetist. The method of Bland and Altman was used to compare differences between AMG and EMG data.

Results: During recovery from neuromuscular blockade, fade was no longer visible clinically $38.6 \pm 10.4 \text{ min}$ (mean \pm SD) after the administration of vecuronium. This corresponded to

TOF ratios of 0.40 ± 0.23 by AMG and 0.34 ± 0.21 by EMG. Usually, two twitches were visible before AMG detected the first twitch. The time to TOF ratio ≥ 0.7 by AMG and EMG was similar at 49.1 ± 10.5 and $50.9 \pm 9.0 \text{ min}$, respectively. The bias between AMG and EMG was one minute, with limits of agreement from -10 to nine min.

Conclusion: AMG is superior to visual assessment in detecting residual neuromuscular block and provides similar estimates of recovering block as the more cumbersome EMG.

Objectifs: Déterminer si l'accélérographie améliore la détection de la curarisation résiduelle. Un deuxième objectif consistait à comparer les données accélérographique à celles de l'électromyographie.

Méthodes: Vingt-deux enfants anesthésiés qui avaient reçu vecuronium $0,1 \text{ mg} \cdot \text{kg}^{-1}$ iv ont pris part à cette étude aléatoire, prospective et en double aveugle. Dans le but de mesurer les réponses de l'adducteur du pouce au TOF du nerf cubital, l'évaluation de la profondeur de la curarisation a été débutée 10 min après l'injection et été répétée à toutes les minutes à l'aide d'un accélérographe (Biometer, Tofguard) sur une main et une stimulation au train-de-quatre (TOF) sur l'autre. Le monitoring a été arrêté au moment où l'affaiblissement de la réponse (fade) est disparu et où la relation TOF $\geq 0,7$. L'anesthésiste responsable a comparé les données électromyographiques (EMG) et accélérographiques (AMG) en observant au niveau du pouce le nombre de twitches et l'affaiblissement de la réponse. La méthode de Bland et Altman a été utilisée pour comparer les différences entre les données AMG et EMG.

Résultats: Pendant la récupération, l'affaiblissement n'était pas visuellement détectable $38,6 \pm 10,4 \text{ min}$ (moyenne \pm ET) après l'administration du vecuronium. Ceci correspondait à des rapports TOF de $0,40 \pm 0,23$ mesurés par AMG et $0,34 \pm 0,21$ par EMG. En général, deux twitches étaient visibles avant la détection par AMG du premier twitch. L'intervalle jusqu'au rapport TOF $\geq 0,7$ était identique, respectivement de $49,1 \pm 10,5$ et $50,9 \pm 9,0 \text{ min}$. Le biais entre AMG et EMG était de une min, avec des limites d'accord de -10 à neuf min.
Conclusion: L'AMG est supérieure à l'évaluation visuelle pour détecter la curarisation résiduelle et fournit des données comparables à celles de l'EMG lequel est plus encombrant.

Key words

ANAESTHESIA: paediatric;
MONITORING: neuromuscular function;
NEUROMUSCULAR RELAXANTS: complications, residual block.

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Ventilatory function, assessed by measurements of peak inspiratory flow, is considered to be restored when the train-of-four ratio (TOF) of the adductor pollicis in response to ulnar nerve stimulation exceeds 0.7 during recovery from d-tubocurarine¹ or pipecuronium² neuromuscular blockade. This value has become the standard at which to aim to ensure adequate recovery from non-depolarizing neuromuscular block. Unfortunately it is difficult, if not impossible, to detect small degrees of TOF fade using visual or tactile observations.³⁻⁵ The use of double burst stimulation has reduced, but not eliminated, the magnitude of the discrepancy between clinical estimates and recorded observations of elicited responses.⁴⁻⁷ However, more sensitive measurements using mechanomyography (MMG) or electromyography (EMG) are difficult to introduce into routine clinical practice because they are time-consuming and require bulky, expensive equipment.⁵

The assessment of the degree of neuromuscular block by measurement of the acceleration of the thumb in response to ulnar nerve stimulation has recently been introduced into clinical practice.^{8,9} Accelomyography (AMG) is no more difficult or time-consuming to apply than a peripheral nerve stimulator, which is recommended for routine clinical practice. Therefore, AMG may have wider applicability than the mechanomyogram (MMG) or electromyogram (EMG). In addition, it produces a signal that is displayed digitally into a liquid crystal display, allowing it to be integrated into an automated anaesthesia record. It has also been shown that use of AMG prevented the development of residual blockade when it was used to evaluate recovery from pancuronium-induced neuromuscular blockade.¹⁰

The purpose of the present study was to compare the use of AMG with clinical evaluation of recovery from vecuronium-induced neuromuscular block in children during anaesthesia. In addition, AMG measurements were compared with simultaneous EMG measurements obtained from the contralateral hand.

Methods

After institutional ethics committee approval and informed parental consent, 29 children, aged 2–10 yr and ASA physical status 1 or 2, were enrolled into the study. They were admitted for elective day care surgery under general anaesthesia for dental restorative procedures with anticipated durations of at least one hour. None was receiving medication or suffered from disease known to affect neuromuscular transmission.

Children who were upset or anxious on admission received premedication of midazolam 0.5 mg·kg⁻¹ *po* 15–30 min before surgery. On arrival in the operating room, routine monitoring (electrocardiogram, non-inva-

sive blood pressure recording, pulse oximetry and axillary temperature) was applied. The blood pressure cuff was placed on the leg. Local anaesthetic cream on the dorsum of the hand facilitated insertion of an intravenous cannula, which was located on either hand and attached to an extension tube to provide a remote injection site for injection of drugs or saline to flush the line. Anaesthesia was induced with propofol 3–5 mg·kg⁻¹, lidocaine 0.3 mg·kg⁻¹ and fentanyl 2–3 µg·kg⁻¹ *iv*, followed by maintenance with inhalation of isoflurane (0.5–1% inspired concentration), nitrous oxide 70% and oxygen mixtures. Nasotracheal intubation was performed without the use of relaxants, using an uncuffed nasotracheal tube. The lungs were ventilated to maintain normocapnia based on end-tidal carbon dioxide concentrations measured by capnometry. On completion of the study period, anaesthesia was conducted at the discretion of the attending anaesthetist until the end of surgery.

Patients were assigned randomly to have the EMG or AMG positioned on the left or right hand. Stimulating surface electrodes were applied over the ulnar nerves in the forearm near the wrists of both hands. Palmar skin temperatures were monitored and skin temperature was maintained ≥34°C. The EMG recording electrodes were applied over the adductor pollicis muscle of one hand and the AMG transducer was applied to the opposite hand on the palmar surface of the distal phalanx of the thumb. Both arms were wrapped in towelling to maintain limb temperature and dorsal splints were used to immobilize the forearms and fingers, but free movement of the thumb was ensured for the AMG monitor. Supramaximal stimuli of 0.1 msec duration in TOF mode at 2 Hz were applied every 20 sec for the EMG, using the Datex Relaxograph NMT 100 (Datex Instrumentarium Corporation, Helsinki, Finland) and every 15 sec for the AMG, using the Tofguard^{INMT} (Biometer International A/S, Odense, Denmark) monitors. After ten minutes stabilization, the neuromuscular monitors were calibrated.

After repeat calibration, vecuronium 0.1 mg·kg⁻¹ *iv* was administered, taking care to avoid moving the hand into which the injection was made. Ten minutes after the administration of vecuronium, when neuromuscular blockade was established, measurements of first twitch height (T₁) and TOF fade were commenced and made simultaneously by AMG, EMG and visual estimates of thumb movement, on the same side as the AMG, by one of three participating attending anaesthetists who was blinded to the monitor displays. These observations were repeated at one minute intervals, during recovery from neuromuscular blockade, until TOF fade was no longer detectable clinically and monitoring by AMG

and EMG showed T_1 height recovery $\geq 70\%$ of control and TOF ratio ≥ 0.7 , or these values had reached a plateau and showed no further recovery on three consecutive readings.

Data were collected during the study period on a computer-based spreadsheet (Microsoft Excel V5.0). Demographics (date of birth, weight, height, sex) and times of induction of anaesthesia, administration of vecuronium, onset and cessation of monitoring were recorded. Entries of data for T_1 and TOF ratios, monitored by AMG or EMG, and estimated visually, were made at the time of monitoring. Values are expressed as mean \pm SD. Statistical analysis was performed using paired Student *t* test, chi-squared analysis and Fisher exact test where appropriate. Agreement between the monitors was assessed by the methods of Bland and Altman.^{11,12} These assess the extent of the agreement between two different methods of clinical measurement by calculating the mean of the differences between the values obtained by the two methods (bias) and the SD of the differences. Simple plots of the simultaneous recordings of measurements by EMG and AMG and their lines of identity, and plots of the mean of the two values against the difference between the paired measurements were used for this method of analysis.

Results

Data collection was completed on 22 of 29 children who were enrolled into the study: seven were excluded from analysis because surgery ended before the study could be completed in four and EMG recordings were unsatisfactory in three patients. The 22 patients studied were 11 boys:11 girls, aged 5 ± 1.6 yr and weighed 20.3 ± 5.3 kg.

Recovery of first twitch

First twitch response usually appeared first on the EMG and was present before any twitches were visible. Estimates of recovery of T_1 by the visual observation of the thumb by the anaesthetist or return of EMG activity preceded the AMG response. On average, two twitches of the thumb were observed before the first twitch appeared on the AMG response (Figure 1).

Recovery of train-of-four

During recovery from neuromuscular blockade, fade of TOF was no longer visible 38.6 ± 10.4 min after the injection of vecuronium, when the measured TOF ratio was 0.40 ± 0.23 by AMG and 0.34 ± 0.21 by EMG. All except three of the EMG values were < 0.5 . On recovery of the TOF to > 0.7 , measured by AMG, only one child still showed a TOF ratio < 0.5 by EMG (Figure 2).

There were 568 paired values for the TOF ratios mea-

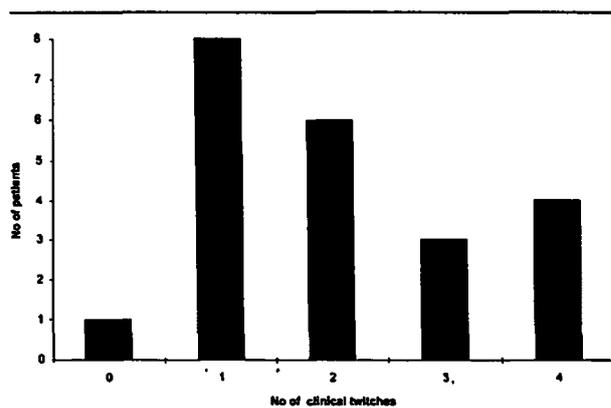


FIGURE 1 Distribution of the number of twitches seen on visual inspection clinically when the first twitch is detected by AMG monitoring.

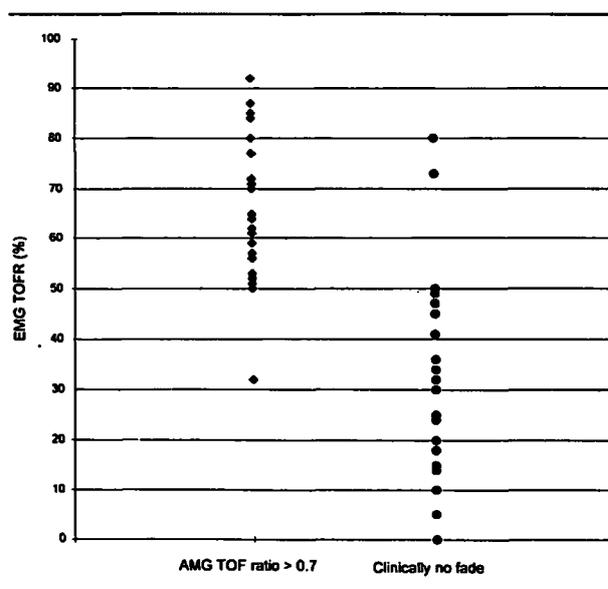


FIGURE 2 Value of TOF ratio monitored by EMG when the AMG shows a TOF ratio > 0.7 and when no fade was detected clinically.

sured by AMG and EMG (Figure 3). Plots of the difference between the paired measurements against the mean (Figure 4), showed that the bias between the sensors was 0.03, with AMG higher than EMG. Limits of agreement were -0.26 to 0.32 and the 95% confidence interval for the bias was $0.02-0.04$.

The interval between administration of vecuronium and spontaneous recovery of TOF ratio to > 0.7 was similar when monitored by AMG or EMG, at 49.1 ± 10.5 and 50.0 ± 9.0 min, respectively (Figure 5). The bias between the sensors was one minute (AMG reaching TOF > 0.7 earlier than EMG) with limits of agreement from -10 to 9 min (Figure 6) and 95% CI for the

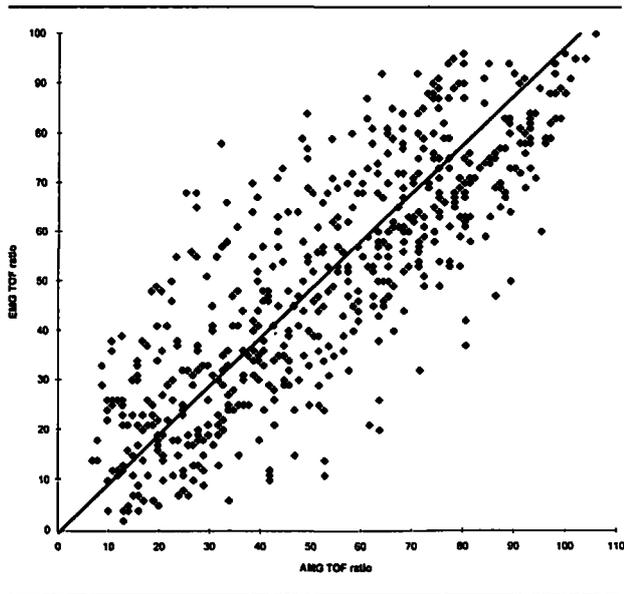


FIGURE 3 Comparison of TOF ratios monitored simultaneously by EMG and AMG at all measurement points and line of identity.

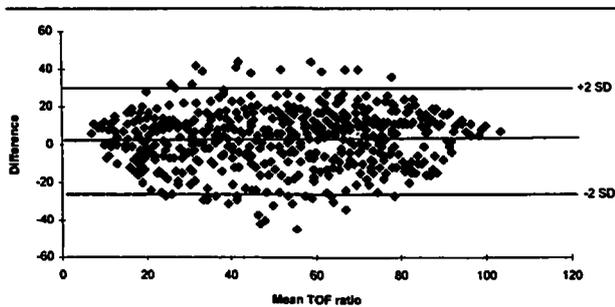


FIGURE 4 Difference between TOF ratios measured by AMG and EMG (as shown in Figure 3) plotted against their means, with limits of agreement indicated.

bias of -1.0 -3.0 min. When the TOF ratio was >0.7 by EMG, the mean TOF ratio by AMG was similar at 0.72 ± 0.14 (range: 0.39 – 0.93).

Discussion

This study confirmed that fade in response to TOF stimulation was no longer visible 10 min before the TOF ratio was restored to the "gold standard" of 0.7 when monitored by AMG or EMG. Furthermore, the TOF ratio is 0.4, whether monitored by AMG or EMG, despite apparent return to full recovery by clinical evaluation. These results suggest that there is a period of vulnerability during which a patient may be assumed to have recovered, but residual neuromuscular blockade is present to an extent which can compromise respiratory efforts. It is now recognised that return to a TOF ratio of

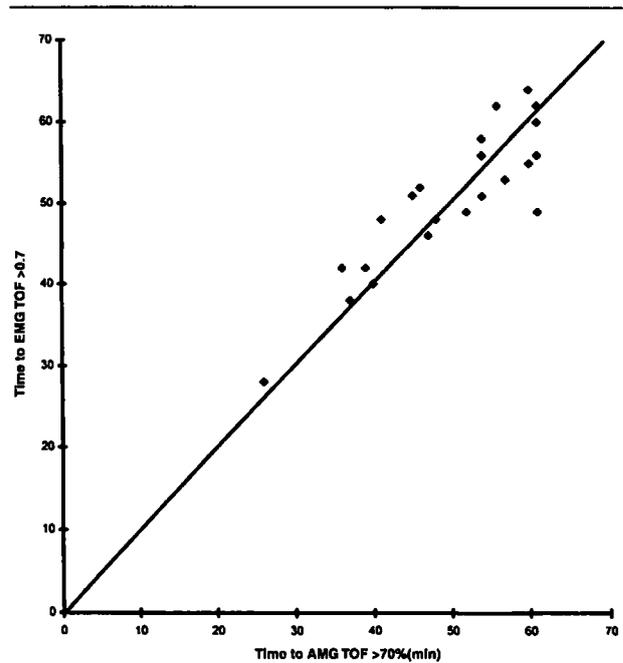


FIGURE 5 Times from injection of vecuronium $0.1 \text{ mg} \cdot \text{kg}^{-1} \text{ iv}$ to recover to TOF ratios >0.7 as assessed by AMG and EMG with line of identity shown.

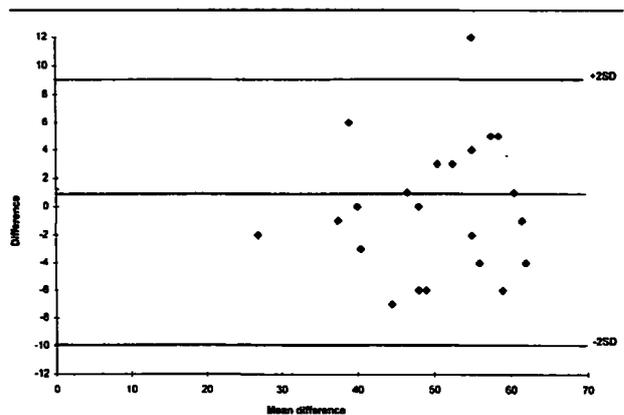


FIGURE 6 Difference between time (min) to reach TOF ratio >0.7 measured by AMG and EMG plotted against the mean of the differences with limits of agreement shown.

0.7 may be a conservative estimate of the degree of recovery which is desirable at the end of surgery.^{5,13} Ventilatory depression may be seen until nearly complete recovery of TOF ratio to ≥ 0.9 so that this period of vulnerability may be longer than ten minutes, even for a neuromuscular relaxant of intermediate duration, such as vecuronium.

Care was taken to minimize differences between the output of the two monitors due to study conditions.

Electrode positioning was constant¹⁴ and movement of the arm from blood pressure measurement or tactile evaluation was avoided. A continuous infusion was not given, to minimize temperature changes. Repeated visual assessment of TOF response by the same observer may have introduced bias, but the observer was blinded to the AMG or EMG recordings. Tactile assessment was not made, but gives similar results to visual assessment.³⁻⁵ Variations in responses from different arms were avoided by randomization of the monitors to right or left arm. The characteristics of the monitors meant that AMG stimulation was applied every 15 sec while that of the EMG was at 20 sec intervals. The faster rate may intensify a measured block, but is unlikely to have influenced the detection of TOF fade appreciably.¹⁵

The finding in the present study that fade of TOF ratio <0.4 was not detected by visual observation agrees with previous studies, which have consistently shown that the ability to detect small degrees of fade clinically is unreliable and not improved by experience.³ The ability to detect residual neuromuscular blockade by tactile assessment of fade with double burst stimulation offers only modest improvement.⁴⁻⁷ Two previous studies compared the AMG with the mechanomyograph (MMG)^{16,17} or EMG.¹⁸ Comparisons were made using regression analysis or correlation coefficients and it was concluded that the two monitoring methods gave disparate results. In the present study comparisons were made by using the approach of Bland and Altman.^{11,12} The limits of agreement of the TOF ratio of 0.4 to 0.9 were found to be similar to those in the earlier studies,¹⁸ but the interpretation differs. In contrast to previous views, we consider that these limits of agreement between EMG and AMG are very acceptable when compared with their wide discrepancy with clinical assessment.

Limits of agreement in terms of time are, perhaps, more clinically relevant than is the TOF ratio. For example, with continuous monitoring following the administration of vecuronium, when the TOF ratio was >0.7 by AMG, the TOF ratio would exceed 0.7 by EMG in more than 95% of children after a further ten minutes. The major advantage of the AMG over the MMG and EMG is that it is as easy to use as a standard peripheral nerve stimulator. In all patients, the AMG was calibrated at the first attempt and readjustment was not required, while three patients were withdrawn from the study due to difficulties in obtaining an adequate EMG calibration, and readjustment was required in several others. The findings of this study only apply directly to children following the use of vecuronium and may not be reproduced in different age groups and with other muscle relaxants. However, it is likely that differences

will result in longer or shorter "periods of vulnerability" resulting from the variable rates of recovery of different neuromuscular blocking agents or rates at different ages.

The EMG is impractical as an alternative to visual or tactile assessment of recovery from neuromuscular blockade in the operating room. Even if the TOF ratio were monitored by EMG, the degree of recovery which is adequate is controversial,¹⁹⁻²¹ and the use of a TOF ratio >0.7 to indicate adequate clinical recovery and <0.5 as an indicator of important residual neuromuscular blockade, may be conservative. Although monitoring by either the AMG or the EMG resulted in improved detection of residual neuromuscular blockade in the children studied, the AMG had the advantage of ease of use and was more dependable in its monitoring performance. Experience in adults is limited, but the use of AMG monitoring reduced the incidence of residual neuromuscular blockade after pancuronium administration.¹⁰ It is concluded that the AMG is superior to clinical assessment in the detection of residual neuromuscular block in children. It is easy to use and provides an assessment of TOF ratio which is as useful as EMG monitoring.

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