



## Comparison of clinical validation of acceleromyography and electromyography in children who were administered rocuronium during general anesthesia: a prospective double-blinded randomized study

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**Background:** Electromyography and acceleromyography are common neuromuscular monitoring devices. However, questions still remain regarding the use of acceleromyography in children. This study compared the calibration success rates and intubation conditions in children after obtaining the maximal blockade depending on each of the devices

**Methods:** Children, 3 to 6 years old, were randomly allocated to the TOF-Watch SX acceleromyography group or the NMT electromyography group. The induction was performed with propofol, fentanyl, and rocuronium. The bispectral index and 1 Hz single twitch were monitored during observation. The calibration of the each device was begun when the BIS dropped to 60. After successful calibration, rocuronium 0.6 mg/kg was injected. A tracheal intubation was performed when the twitch height suppressed to 0. The rocuronium onset time (time from administration to the maximal depression of twitch height) and intubating conditions were rated in a blinded manner.

**Results:** There was no difference in the calibration success rates between the two groups; and the calibration time in the electromyography group ( $16.7 \pm 11.0$  seconds) was shorter than the acceleromyography group ( $28.1 \pm 13.4$  seconds,  $P = 0.012$ ). The rocuronium onset time of the electromyography group ( $73.6 \pm 18.9$  seconds) was longer than the acceleromyography group ( $63.9 \pm 18.8$  seconds,  $P = 0.042$ ) and the intubation condition of the electromyography group ( $2.27 \pm 0.65$ ) was better than the acceleromyography group ( $1.86 \pm 0.50$ ,  $P = 0.007$ ).

**Conclusions:** Electromyography offers a better compromise than acceleromyography with respect to the duration of calibration process and surrogate for the optimal time of tracheal intubation in children.

**Key Words:** Acceleromyography, Electromyography, Neuromuscular monitoring, Preschool child, Rocuronium.

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## Introduction

Mechanomyography (MMG) is known to be the most accurate among the neuromuscular monitoring devices [1-3], but it is relatively big and difficult to apply, so its clinical use is limited. Hence, devices that are easier to apply, such as acceleromyography (AMG) and electromyography (EMG), are used more often clinically. Although AMG can be a useful method for the measurement of neuromuscular blockade in neonates and infants [4,5], several studies have shown that AMG is less precise than EMG [6-8]. Moreover, we have encountered a technical problem in getting a proper baseline calibration of a single twitch of AMG before administration of a neuromuscular blocking agent in children. Thus, there remains questions regarding the applicability of AMG to children [3]. The present study is an attempt to determine the optimal time of tracheal intubation, according to the AMG or EMG derived maximal depression of twitch height. The aim of the present study is to compare the validity between the AMG and EMG as applied to children.

We hypothesized that there would be no difference of intubation conditions between the two groups of AMG and EMG. Based on the outcome of a previous study, the intubation condition was set as the primary endpoint. Other observations (calibration process of each device, duration of calibration, and onset of neuromuscular blockade) were set as the secondary endpoints. To test this hypothesis, we compared the intubating conditions when the maximum neuromuscular blockade had been attained by the devices.

## Materials and Methods

This study was approved by the Institutional Review Board of our hospital. The objective and methods of the study were clearly explained to all parents or guardians and the written informed consents were obtained. The randomized double-blind study involved 100 patients who were selected with the following criteria: 3–6 years aged children with American Society of Anesthesiologists physical status I-II who were scheduled for elective surgery under general anesthesia. The excluded patients were those with a known neuromuscular disease, renal dysfunction or who were taking a medication that interacts with rocuronium, or had a family history of malignant hyperthermia.

Before leaving the general ward, 20–40 minutes before induction, atropine 0.1 mg/kg was injected intramuscularly to the patient. The patient was sedated with propofol 1 mg/kg intravenous administration at the surgery waiting room in a stable state, and transferred to the operating room. Fentanyl 0.5 µg/kg was injected intravenously, and then hemodynamic monitoring devices and bispectral index (BIS) monitor (BIS-Vista monitors, Aspect Medical Systems, Newton, MA, USA) were applied. They

were randomly allocated to the TOF-Watch SX group (Organo (Ireland) Ltd., Drynam Road, Swords, Co. Dublin, Ireland) (group T) or the NMT group (S/5™ Anesthesia Monitor, E-NMT-00, M1026236 EN, NMT electrosensor REF 888416, GE Healthcare, Datex-Ohmeda, Helsinki, Finland) (group N). Randomization was made by means of a random number table, and the group allocation was determined by opening a sealed envelope.

All patients were placed under forced warm air heating blanket (Bair Hugger; Augustine Medical Inc., Eden Prairie, MN, USA) and the skin temperature of monitoring hand was maintained at > 32°C to avoid changes in skin impedance and muscle responsiveness to electrical stimulation. The study arm and wrist were fixed to rigid arm boards, but the thumb was free to move. The skin over the ulnar nerve was first cleaned, degreased with an alcohol swab, and dried before the application of electrodes.

The electrodes for each group were applied to an appropriate location, in accordance with the manufacturers' guidelines, and for the group that a patient was allocated to. In group T, the stimulating electrodes (3M™ Red Dot™ Repositionable Monitoring Electrode 2660-3 (3M, St. Paul, MN, USA) were placed over the ulnar nerve on the volar side of the wrist. The distal electrode was positioned where the proximal bending line crosses the radial side of the flexor carpi ulnaris muscle. The proximal electrode was placed 2 to 3 cm proximal to the distal electrode over the ulnar nerve. In group N, the distal recording electrode (NMT electrodes Ag/AgCl hydrogel adhesive REF 57268-HEL, GE Healthcare Finland Oy, Helsinki, Finland) was attached on the radial side of the second proximal phalanx, and, the proximal recording electrode was placed on the thenar prominence. The reference electrode was placed on the skin at the center of the flexor crease. The distal stimulating electrode was positioned 2 to 3 cm proximal to the point where the flexor crease crosses the radial side of the flexor carpi ulnaris muscle. The proximal stimulating electrode was placed 2 to 3 cm proximal to the distal electrode over the ulnar nerve. An acceleration transducer was attached with surgical tape to the flexor aspect of the freely mobile thumb. In group T, the movement of other fingers was restricted in the extension position with tape. No preload was employed for all subjects. The monitoring arm of the patient and monitoring devices were screened with drapes to prevent the intubation practitioner or observer from verifying the device.

Five minutes after the first administration of propofol, IV propofol 2 mg/kg was injected for induction. When the BIS dropped to 60, the calibration of 1 Hz single twitch of the each neuromuscular monitoring device was begun, following the manufacturers' guidelines for using its automatic start-up procedures. Supramaximal current was determined automatically for each device. The single twitch height (TH) % of each device was used as reference value for all measurements. After 100% stabi-

lization of control height, rocuronium 0.6 mg/kg was injected intravenously. The tracheal intubation was done when the TH suppressed to 0. To avoid biases, all intubations were done by one experienced practitioner. When the stabilization of the first calibration was not obtained, a second calibration of each device was performed in a same fashion. In the case of a BIS increase over 70 during the whole observation period, sevoflurane 3% was administrated by manual ventilation and the patient was excluded from the study. The BIS scores were recorded at five different time points. These five points are: at the baseline (before induction), after finishing the calibration process, after an intravenous rocuronium injection, during tracheal intubation, and after intubation.

## Outcome measures

The primary outcomes were the rocuronium onset time and intubating conditions. The rocuronium onset time was measured by seconds from the intravenous administration of rocuronium to the TH suppressed to 0. The intubating condition was rated by an intubation practitioner on a three-point scale (excellent, good, or poor), according to grading scale described by International Consensus Conference held in Copenhagen in 1994 (Table 1). The secondary outcomes were the success rates of calibration, duration of calibration, cause of calibration failure.

## Statistics

The patient data are presented as mean  $\pm$  SD or number of patients. A power analysis suggested that a minimum sample size of 45 patients for each group would be required with a significance level of 5% to achieve a power of 80%. It was calculated from the pilot attempt to determine the significant difference of the proportion of validity.

We found that the proportion of excellent intubating conditions could be observed less than one out of five trials when the tracheal intubation was performed after the twitch height

suppressed to 0 for group T (proportion of group T is less than 0.001), whereas, it was one of five trials for group N (proportion of group N is 0.2). Because of the low numbers categorized as poor, the intubating conditions were graded as 'excellent' versus 'other' for a statistical comparison of the proportion comparison. The study population was prospectively set at 100 patients, considering the exclusion rate.

The analyzed data were tested for normality by the Shapiro-Wilk or Kolmogorov-Smirnov test. Depending upon the results of the normality test, either a parametric or non-parametric analysis was performed. The statistical analyses were performed using the Statistical Package for Social Sciences, version 12.0 (SPSS, Chicago, IL, USA). Comparisons between the groups were performed with an unpaired Student t-test for parametric data; differences among the BIS scores from the baseline to observation points in each group were tested with ANOVA and with Dunn's multiple comparisons. Relation between rocuronium onset time and intubation conditions in each group were analyzed with linear regression. Some demographic data, as well as sex and the success rate of the calibration, were analyzed using the Chi square or Fisher's exact test. A P value  $<$  0.05 was considered statistically significant.

## Results

There was no statistically significant difference in the success rate of calibration between the two groups. The average of duration of calibration in group N was  $16.7 \pm 11.0$  seconds, which was significantly shorter than  $28.1 \pm 13.4$  seconds of group T ( $P = 0.012$ ) (Table 2). In group T, the most common cause of calibration failure was an unstable transducer, which affected eleven patients. Whereas, in group N, the most common cause of calibration failure was high resistance, which affected ten patients. The BIS increased over 70 during the observation period for one patient of group T and two patients of group N; hence they were excluded from the study (Table 3).

The onset time of rocuronium in group T was shorter than

**Table 1.** Assessment of Intubating Conditions

Variables	Intubating conditions		
	Acceptable		Unacceptable Poor
	Excellent	Good	
Ease of laryngoscopy (jaw relaxation)	Easy	Fair	Difficult
Vocal cord position	Abducted	Intermediate	Closed
Vocal cord movement	None	Moving	Closing
Airway reaction (coughing)	None	Diaphragm	Sustained ( $>$ 10 sec)
Movement of the limbs	None	Slight	Vigorous

Intubating conditions; Excellent: all criteria are 'excellent', Good: all criteria are either 'excellent' or 'good', Poor: the presence of a single criterion listed under 'poor.'

**Table 2.** Calibration Success Rate and Time

	TOF Watch SX group (n = 49)	NMT group (n = 48)	P value
Success rate of 1 <sup>st</sup> calibration (%)	46.9% (23/49)	64.5% (31/48)	> 0.8
Success rate of 2 <sup>nd</sup> calibration (%)	61.2% (30/49)	79.1% (38/48)	> 0.8
Calibration time (sec)	28.1 ± 13.4	16.7 ± 11.0	0.012

Data are number of patients or mean ± SD. The average of the first and second success rate was similar in both groups (P value > 0.8), but calibration time of the group N (16.7 sec) was significantly shorter than group T (28.1 sec) (P value = 0.012). TOF Watch SX group: acceleromyography, Group T: NMT group, Electromyography: Group N.

**Table 3.** Causes of Calibration Failure

Cause of failure	TOF Watch SX group (n = 49)		NMT group (n = 48)	
	1 <sup>st</sup> calibration	2 <sup>nd</sup> calibration	1 <sup>st</sup> calibration	2 <sup>nd</sup> calibration
High resistance	4	4	12	10
Unstable transducer	16	11	0	0
Involuntary movement	6	4	5	0

TOF Watch SX group: acceleromyography, Group T: NMT group, Electromyography: group N.

**Table 4.** Comparison of BIS, Onset Time of Rocuronium and Intubation Condition

	TOF Watch SX group (n = 49)	NMT group (n = 48)	P value
BIS at			
Baseline	81.6 ± 10.0	85.9 ± 9.9	0.066
Calibration	50.8 ± 7.7	54.6 ± 10.1	0.072
Rocuronium injection	53.1 ± 9.0	55.4 ± 10.7	0.356
Intubation	57.9 ± 5.4	62.1 ± 7.7	0.017
After intubation	60.1 ± 5.6	65.1 ± 6.5	0.003
Onset time (sec)	63.9 ± 18.8	73.6 ± 18.9	0.042
Intubation condition	1.86 ± 0.50	2.27 ± 0.65	0.007

The rocuronium onset time was measured by seconds from the intravenous administration of rocuronium to the twitch height suppressed to 0. The classification of the intubation conditions, as excellent, good, and poor, following the criteria shown in Table 1 were measured as scores 3, 2, and 1, respectively, and statistical calculations were performed. TOF Watch SX group: acceleromyography, Group T: NMT group, Electromyography: group N.

for group N (P = 0.042). There were no failed intubations. The proportion of patients with satisfactory (excellent or good) intubating conditions was similar in both groups (76% in group T; 89% in group N) (P = 0.272). However, the proportion of patients with excellent intubating conditions in group N (39%) was significantly greater than group T (6%) (z = 2.86, 95% confidence interval; -0.536 to -0.124, P = 0.004). The classification of the intubation conditions, as excellent, good, and poor, was measured as scores 3, 2, and 1, respectively, and statistical calculations were performed. The average of intubation conditions in group T was 1.86 ± 0.5, and it was lower than 2.27 ± 0.6 of group N (P = 0.007). There was no observed relation between the intubation conditions and rocuronium onset time. The coefficient of determination R<sup>2</sup> equals nearly 0 (0.0688 in group T; 0.0186 in group N) and the power of the performed test with alpha (0.286 in group T; 0.109 in group N) in each group is below the desired

power of 0.8. Compared with group N, the poorer intubation conditions were observed as the rocuronium onset time decreases in group T (Table 4).

The BIS scores of group T were lower than group N at the time point of intubation (P = 0.007) and after intubation (P = 0.003).

## Discussion

In this study, we compared the clinical validity and usefulness of AMG and EMG for neuromuscular monitoring in children. The findings showed that the duration of stabilization for calibration of EMG is shorter than AMG, and satisfactory excellent intubation conditions were achieved in the great majority of the group N rather than group T.

The calibration failure rate can be lowered by avoiding most

common causes of calibration failures, as well as a decrease in total calibration time, and the usability of the devices can be improved. The different matters are required for installation of the different measuring techniques. The AMG was affected by stabilization of transducers [9], whereas the EMG was more affected by skin resistance than the AMG. In the present study, the calibration time of the AMG is significantly longer than the EMG. One possible explanation is the difference of sensitivity between the two devices. That is, the EMG can detect muscle activities more sensitively than the AMG [6,9,10]. Additionally, the EMG can yield more consistent responses because it is not affected by restriction of a movement of a muscle [9,11]. The AMG may need a higher stimulation current to properly detect muscle contractions than the EMG. Another possible explanation is that the difference of calibration time might be caused by the software programs that each device uses for calibration sequences. The findings from the present study are consistent with the study by Driessen et al [4]. They could automatically obtain the 100% of T1 in nine out of total of 22 infants during the calibration process when monitored by the AMG (success rate of the first calibration was 41%). Also, we recommend the cleansing skin with isopropyl alcohol or use of a good quality electrode, such as the Ag/AgCl hydrogel adhesive backed electrode, which can lower the impedance and ensure a proper skin resistance [12]. Careful preparation increases the success rate of the calibration process and decreases the duration of the total stabilization process.

There are several studies to compare the AMG to that EMG [7,9,13]. To the best of our knowledge, none of these papers compared the success rate or the duration of the baseline calibration of devices for children. We think that the sufficient time of the stabilization process after baseline calibration is required to get a reliable reference value of the twitch height before the neuromuscular blockade administration. However, this time-consuming process usually makes it difficult to determine the time of tracheal intubation in case of a rapid sequence induction without addition of inhalational or intravenous anesthetics.

Even after the successful installation and baseline calibration of each device, the average score of intubation conditions of the Group N is better than the Group T. In general, intubating conditions are influenced both by the anesthesia depth indicators and the degree of muscle relaxation [14,15]. In the present study, we administered the same induction agents and used a dose of rocuronium, which was known to produce a maximal

neuromuscular block within 2 minutes [16-18]. Under these same conditions, there can be little doubt that the main factor producing excellent intubating conditions was the high degree of neuromuscular block at intubation. However, these results showed that even at the maximal blockade of a single twitch height by the AMG or EMG, the differences in monitoring devices can have a significant effect on intubating conditions. One of possible explanations of this lack of validity for the AMG is its lower sensitivity than the EMG [9,13,19]. The T1 seems to have measured fine muscle contractions as zero with the AMG because the AMG couldn't detect these contractions, whereas the EMG could. The results of present study support this hypothesis in which the EMG had significantly longer onset time than the AMG. In a similar study with adult patients, the AMG was also less sensitive than the EMG [9]. Another possible explanation of this lack of validity is the anesthetic depth. In this present study, the intubation was performed later in the Group N than the Group T, after the administration of rocuronium. Similarly, the BIS score at intubation in the Group N was higher than the Group T. This means a lighter anesthetic depth for the Group N as opposed to the Group T. In general, a lighter anesthetic depth can cause poorer intubation conditions [20,21]. But in this present study, the Group T with a lower BIS score (i.e., deeper anesthetic depth) was observed with poorer intubation conditions. Thus, the difference in anesthetic depth between the two groups in this study is a less probable cause for the lack of validity. Actually, the BIS scores of two groups varied between 57 and 62 at the intubation time. We think that the difference of the BIS scores between the two groups could be considered negligible with that range. A practitioner's intubating skill or a patient's age could also affect the intubation conditions [22,23]. In this present study, one practitioner performed all intubations of the study cases and the patients' age was standardized.

We conclude that the reliable calibration of a neuromuscular monitoring device followed by the final baseline of twitch height of a thumb can be used as a reference for the onset time of neuromuscular blockade by rocuronium in children. Electromyography is better than acceleromyography in the aspect of the shorter duration of calibration and surrogate for the optimal time of tracheal intubation. However, whatever the monitoring devices, the success rate of the calibration process and reproducibility will be primarily determined by careful installation and preparation.

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