Original Article

Tolerance to preoperative placement of electrodes for neuromuscular monitoring using the Tetragraph™

ABSTRACT

Background: Quantitative train-of-four (TOF) monitoring has recently been shown to be feasible in infants and children using a novel electromyography (EMG)-based monitor with a pediatric-sized self-adhesive sensor. However, placement of the sensor and initiation of TOF monitoring may require additional time in the operating room (OR), delaying workflow and the time to induction of anesthesia. The current study evaluates the feasibility of placing the self-adhesive sensor in the preoperative holding area in pediatric patients before arrival to the OR.

Methods: Consented pediatric patients undergoing inpatient surgery requiring the administration of NMBAs were enrolled. The EMG electrode was placed along the ulnar nerve on the volar aspect of the distal forearm to provide neurostimulation. After the induction of anesthesia, monitoring was initiated and TOF recording started before the administration of the NMBA. A Likert score (0-10) was used to assess ease of placement, tolerability of the monitor during the preoperative period, and its ability to generate a recorded response in the OR.

Results: The final study cohort included 40 patients with a median age of 3.7 years. Fourteen patients (35%) pulled off the sensor before arrival to the OR and 26 patients (65%) arrived at the OR with the sensor intact and functioning. Older children were more likely to maintain the sensor until arrival to the OR compared to younger patients (median age of 5.24 versus 1 year, $P = 0.0521$). A median age of 3.7 years correlated with an 80% chance of arriving in the OR with the sensor intact. Application ease and tolerance of the sensor were higher in the group that maintained the sensor until OR arrival.

Conclusion: In patients more than 4 years of age, placement of the self-adhesive sensor for EMG-based TOF monitoring may be feasible. However, in younger patients, additional interventions may be required to achieve a similar success rate.

Key words: Neuromuscular blockade, neuromuscular blocking agents, train-of-four monitoring

Introduction

When neuromuscular blocking agents (NMBAs) are used for intraoperative care, train-of-four (TOF) monitoring can be used to evaluate the patient's initial (baseline) response, guide the need for redosing, and document the efficacy of reversal of neuromuscular blockade.[1-3] TOF monitoring may involve subjective (qualitative) or objective (quantitative) assessment

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of the response following stimulation of the specific muscle group. Subjective assessment involves a visual assessment of the number of twitches of the TOF count (TOFC) using a peripheral nerve stimulator (PNS). Objective (quantitative) measurement of the response of stimulation involves not only counting the number of twitches in the TOF sequence (TOFC), but also a measurement of the twitch heights with a comparison of the fourth TOF twitch (T4) to the height of the first twitch (T1), and a calculation of the ratio (T4/T1 or TOF ratio, TOFR).[3] Quantitative technology for TOF monitoring includes mechanomyography, acceleromyography, or electromyography- (EMG)-based devices. Given the inherent inaccuracies of visual inspection using qualitative monitoring, there has been increased use of quantitative devices during intraoperative care of adults.[4-6] We have recently demonstrated the feasibility of using these novel EMG-based devices in infants and children.[7,8] The use of these devices in smaller pediatric patients has been facilitated by the development of pediatric-specific sensors.[8]

Although the literature suggests that quantitative TOF monitoring can be used effectively to provide an objective measure of the degree of neuromuscular blockade, quantitative monitoring devices can take longer to place and may impact operating room efficiency. In our previous study using the pediatric sensor in a typical clinical setting, baseline data were not obtained from 22% of patients as the sensor was not placed quickly enough following entry into the OR and before the induction of anesthesia and administration of an NMBA.[8] Although the monitor functioned effectively for the case, the initial baseline data regarding onset and twitch height were not obtained. In adults, placement of the TetraGraph™ (Senzime AB, Uppsala, Sweden) device required an average of 19 seconds longer than placement of a PNS qualitative TOF device.[9] Although the impact of such delays may seem nominal, in a busy operating room, delays are generally considered unacceptable. Additionally, in pediatric patients, one may attempt to minimize the delay between the induction of anesthesia, the administration of an NMBA, the provision of bag-valve-mask ventilation, and endotracheal intubation to decrease the incidence of adverse respiratory events.

The clinical impact of these concerns may be one reason that limits the use of TOF or EMG-based devices more specifically in clinical practice. A recent survey demonstrates that qualitative TOF devices are still the most commonly used devices.[10] Although this may be the result of a limited availability of quantitative devices, the survey also found that despite their availability, quantitative devices are still being disregarded.[10] Commonly cited reasons for lack of monitoring include the lack of reliable monitors in smaller pediatric-aged patients; the impact on clinical productivity and the impetus to efficiently move cases along; challenges with calibration of existing acceleromyographic monitors for use in smaller patients; limited clinical and academic exposure to new TOF monitoring technologies including EMG-based devices; and lack of clinical standards and guidelines for the administration of NMBAs and intraoperative monitoring in the pediatric population.[9,10] Given the concern regarding the impact of sensor placement on OR efficiency, the primary objective of this study was to evaluate tolerance to preoperative placement of the adhesive sensor for the Tetragraph™ Neuromuscular Transmission Monitor in pediatric-sized patients ≤12 years of age.

Methods

This study was approved by the Institutional Review Board of Nationwide Children's Hospital date of approval was 14 May 2023. It was registered at clinicaltrials.gov (NCT04475250). Participants were recruited on the morning of surgery in the preoperative surgical area of the main operating room before anesthetic and surgical care and before entering the operating room. Consent was obtained from a parent and assent was obtained if the patient was ≥9 years of age. A convenience sample of patients was selected from the electronic surgical schedule of the day. Demographic data (age, weight, gender) and the planned surgical procedure were collected from the electronic medical record. The choice of anesthetic medications including premedication and type of induction (inhalation or intravenous) was at the discretion of the attending anesthesiologist. Approximately one hour before surgery, the sensor was placed on the patient without stimulation of the muscle or recording of the EMG [Figure 1]. Based on our current clinical practice the sensor was placed on the volar aspect of the forearm with the stimulating electrodes over the ulnar nerve and the sensing electrodes over the abductor digiti minimi or the abductor pollicis [Figure 2].

Once the sensor was attached, a member of the research team used a 0-10 Likert scale to assess the ease of placement of the sensor and patient tolerance of the sensor before arrival in the OR. Additionally, a parent or guardian used a 0-10 Likert scale to assess how well the sensor was tolerated until the patient was transported to the operating room. Once in the

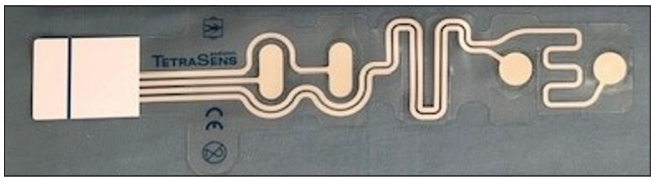

Figure 1: Photograph of the pediatric version of the TetraSens™ self-adhesive sensor for the Tetragraph™ EMG-based quantitative monitor

Figure 2: Pediatric recording electrodes (TetraSens™) attached to the palmar surface of the adductor pollicis muscle and its insertion on the medial aspect of the proximal phalanx of the thumb. The stimulating electrodes were placed along the ulnar nerve on the volar surface of the forearm

operating room, the sensor was attached to the monitor via a standard cable. After the induction of anesthesia, the monitor was activated for calibration and to record the baseline TOF ratio before the administration of the NMBA. Function of the monitor and ability to generate a baseline TOF ratio was graded in the operating room by the anesthesia research team member using the 0-10 Likert scale.

Study data were collected and managed using REDCap (Research Electronic Data Capture) tools hosted at Nationwide Children's Hospital.[11,12] REDCap is a secure, web-based software platform designed to support data capture for research studies, providing an intuitive interface; audit trails for tracking data manipulation and export procedures; automated export procedures for seamless data downloads to common statistical packages; and procedures for data integration and interoperability with external sources. Data collected during this study were stored in secure, password-protected computer files. Only trained members of the research team and collaborators directly involved with the research project had access to the data. Subjects and their information were closely monitored by study staff. For publication, de-identified data are used.

Statistical analysis

Statistical analysis was conducted using SAS 9.4. To assess the normality of continuous variables, the Shapiro-Wilk test was employed. Given the skewed distribution of the data, continuous variables were presented using median and interquartile ranges (IQR). Categorical variables were reported as frequency and percentages. Non-parametric data including the Likert score ratings were summarized and presented using median and IQRs. To analyze the data statistically, a Wilcoxon sum-rank test was performed for between group comparisons of continuous variables while a Chi-square test was utilized to investigate associations among categorical variables. Furthermore, a binary logistic regression analysis was conducted to evaluate the relationship between age and the odds of keeping the sensor intact before entering the OR. A significance level of $P < 0.05$ was applied for all statistical tests.

Results

Fifty-one patients were initially enrolled in the study. Seven patients were excluded for a violation of the study protocol and four patients were not included in subsequent analysis as the sensor was intentionally removed for placement of an intravenous cannula in the extremity or they did not receive rocuronium and hence no intraoperative data was recorded. This resulted in a final study cohort of 40 patients. Fourteen patients (35%) removed the sensor before arrival to the OR and 26 patients (65%) arrived at the OR with the sensor intact and functioning. The demographic data of the entire study cohort and the two sub-groups (those who pulled the sensor off and those arriving at the OR with the sensor intact) are listed in Table 1.

There was a notable trend where younger children had a lower likelihood of maintaining the sensor placement until arrival to the OR compared to their older counterparts. The median age was 0.98 years (IQR: 0.61, 4.89 years) versus 5.24 years (IQR: 0.77, 8.71 years, $P = 0.0521$) when comparing patients who pulled off the sensor to those who arrived with the sensor intact to the OR. In evaluating the ease of sensor application by the research team member between the two groups, the median score in the group that retained the sensor was higher when compared with the group that removed it before arrival in the OR (10; IQR: 7-10 vs. 4; IQR: 0-10; $P = 0.0047$). A similar difference was noted when comparing the Likert scores from the research team member and a parent for how well the sensor was tolerated before transport to the OR [Table 2].

The data were then analyzed in two groups using a median age of 3.7 years to divide the study cohort into two equal groups [Table 3]. The preoperative ease of sensor application assessed by the research team was higher among patients ≥3.7 years of age when compared to those who were less than 3.7 years of age (10; IQR: 10-10 vs. 7; IQR: 1-7.5; $P < 0.0001$). Ten of 20 children (50%) who were less than 3.7 years of age arrived in the OR with the sensor intact versus 16 of 20 children (80%) of children ≥3.7 years of age ($P = 0.0467$). Using binary regression between subject

Table 1: Demographic data of the study cohorts

Variables	Pulled off sensor (n=14)	Sensor intact (n=26)	Entire cohort (n=40)	P (pulled off vs. intact)
Age (years)	0.98 (0.61, 4.89)	5.24 (0.77, 8.71)	3.70 (0.72, 7.90)	0.0521
Gender (female/male)	3/11	6/20	9/31	1
Weight (kg)	9.88 (7.35, 16.90)	20.00 (8.99, 27.40)	15.55 (8.27, 25.35)	0.0916
Height (cm)	73.50 (62.00, 111.90)	110.20 (74.00, 130.30)	103.00 (70.00, 125.50)	0.0481
BMI (m^2)	17.81 (16.33, 19.00)	15.80 (14.71, 18.15)	16.40 (15.16, 18.58)	0.1257
Ethnicity				1
Hispanic	0 (0%)	1 (3.85%)	1 (2.50%)	-----
Non-Hispanic	14 (100.00%)	25 (96.15%)	39 (97.50%)	-----
Race				0.5158
Asian	0 (0%)	2 (7.69%)	2 (5.00%)	-----
Black or African-American	3 (21.40%)	3 (11.54%)	6 (15.00%)	-----
White	11 (78.60%)	19 (73.08%)	30 (75.00%)	-----
Bi-racial/Multi-racial	0 (0%)	2 (7.69%)	2 (5.00%)	-----
ASA class				0.4666
I	3 (21.40%)	11 (42.31%)	14 (35.00%)	-----
II	8 (57.10%)	10 (38.46%)	18 (45.00%)	-----
III	3 (21.40%)	5 (19.23%)	8 (20.00%)	-----
Anesthesia time (mins)	94 (93.00, 140.00)	91.50 (77.00, 125.00)	93.00 (77.00, 140.00)	0.7069
Surgical time (mins)*	52.00 (42.00, 101.00)	47.00 (31.00, 88.00)	47.00 (31.00, 101.00)	0.4049

Data are presented as the median and interquartile ranges or numbers and percentages. OR=operating room; ASA=American Society of Anesthesiologists Physical Classification. *Surgical time includes n=38

Table 2: Comparison of Likert scores across the study cohorts

Variables	Pulled off sensor before arrival in the OR (n=14)	Sensor intact on arrival to OR (n=26)	Entire study cohort (n=40)
Application ease (research team member assessment)	4 (0, 10)	10 (7, 10)*	9.5 (6.5, 10)
Sensor tolerance (research team member assessment)	0 (0, 0)	10 (9, 10)$^+$	9 (0, 10)
Sensor tolerance (family member assessment)	0 (0, 0)	10 (10, 10)$^+$	10 (0, 10)

Data are presented as the median and interquartile ranges. OR=operating room. *P=0.0047; ^+P<0.0001 when comparing sensor intact to sensor pulled off cohorts

Table 3: Comparison of Likert scores across age groups

Variables	Group 1 – age less than 3.7 years (n=20)	Group 2 – age more than 3.7 years (n=20)	P
Application ease (research team member)	7 (1, 7.5)	10 (10, 10)	<0.0001
Sensor tolerance (research team member assessment)	6.5 (0, 9.5)	10 (6.5, 10)	0.0335
Sensor tolerance (family member assessment)	8 (0, 10)	10 (6.5, 10)	0.1464

Median age of 3.7 years was used to separate the study cohort into two even groups of 20 patients. Data are presented as the median and interquartile ranges

status (sensor intact or removed) and age revealed an odds ratio of 1.29 (95% CI: 1.024-1.611). For every 1-year increase in age, the odds of keeping the sensor intact before entering the OR increased by 29%.

Table 4 summarizes the characteristics of neuromuscular monitoring using the TetraGraph™ EMG in patients who arrived in the OR with an intact sensor in place and from whom data was recorded on the built-in secure digital memory card of the TetraGraph™. The data set for these values includes 24 patients, as an effective EMG trace was not obtained from one patient due to the small size (4.2 kg) and there was an error in the device recording from one other patient. The functioning of the monitor as assessed by a member of the research team using a Likert scale (0-10) revealed a median value of 10 and an IQR of 8-10. Automatic detection of a supramaximal stimulus (current amplitude in mA required to initiate a maximal single muscle twitch plus 30%) was obtained with a supramaximal stimulus current intensity of 40-60 mA and a pulse width of 200-300 μsec. The muscle action potential mean baseline amplitude was 9.4 ± 4.2 mV. The average baseline TOF ratio was 99 ± 6%. After antagonism of neuromuscular blockade (data from 20 patients), the baseline amplitude recovered to a mean of 8.2 ± 3.2 mV and the TOF ratio recovered to a mean of 91 ± 9%.

Discussion

The TetraGraph™ is a commercially available, EMG-based quantitative monitor that has been recently introduced to

Table 4: EMG monitoring in the cohort that arrived at the OR with an intact sensor

Parameter	Data results
Baseline TOFr (%)	99±6
Recovered TOFr (%)	91±9
Baseline amplitude (mV)	9.4±4.2
Recovered amplitude (mV)	8.2±3.2

Data are listed as the mean±SD. Recovery data is available from 20 patients. EMG=electromyography; TOFr=train-of-four ratio; SD=standard deviation; mV=millivolts

allow for accurate monitoring of the administration and reversal of NMBAs during perioperative care. Recent concerns regarding the impact of inadequate reversal of neuromuscular blockade have led to recommendations for the increased use of quantitative devices during perioperative care as a means of demonstrating full reversal when NMBAs are used for surgical relaxation.[13,14] The TetraGraph™ uses EMG technology to provide an electrical stimulation to a peripheral nerve and then directly measure the amplitude (muscle action potential) of the evoked responses of the innervated muscle, providing a quantitative measurement of the muscle response to the stimulus. As the EMG is measured and objectively quantified, it eliminates the need for subjective evaluation of the TOF using visual observation of the twitches. In eliminating the visual observation of the twitch response, the quantitative EMG-based monitors provide a more sensitive (less subjective) measure of the degree of neuromuscular blockade and recovery. Additionally, EMG-based devices can be used during surgical procedures in which access to the monitored limb is limited.

The TetraGraph™ device is FDA (Food and Drug Administration) approved for use in adults and children. Preliminary studies have demonstrated its potential utility in pediatric-aged patients during various surgical procedures including laparoscopic procedures where visual observation of the monitored extremity is not feasible due to surgical positioning of the patient.[7,8] In our previous studies, the sensor was placed after the patient was transported to the OR and before the administration of an NMBA. However, we noted that placement of the TetraSens™ Pediatric sensor may take 1-2 minutes thereby delaying the administration of the NMBA or eliminating the ability to obtain baseline data if the NMBA is administered before application of the sensor. To avoid such issues, the current study evaluates the potential utility of placing the TetraSens™ Pediatric sensor following the preoperative evaluation in the holding area before transport to the OR in infants and children. Our initial assessment focused on a cohort of pediatric patients less than 12 years of age, as we felt that this is the age group that frequently undergoes inhalation induction of anesthesia and that placement of the monitor may not be as feasible during this process when compared to intravenous induction where one may pause before the administration of intravenous induction agents and NMBAs to place to the TetraSens™. Success in preoperative placement was correlated with patient age with a median age of 3.7 years defining a threshold for a success rate of 80%. In the current study, success was primarily judged by the patient arriving in the OR with the sensor still in place and not by the accuracy of TOF monitoring data. However, in all but one of the 26 patients who arrived at the operating room with the sensor intact, the monitor functioned.

As we were unable to achieve complete success with preoperative placement of the TetraSens™, additional initiatives would be required to make this a technically sound and cost-effective means to ensure accurate TOF monitoring when the patient arrives to the OR, especially in younger patients. Potential initiatives to improve the success of the technique and limit patient displacing the TetraSens™ may include premedication, closer supervision once the device is applied, wrapping the sensor and involved extremity with gauze, and a shorter time between its application and transport to the OR. It may be feasible, for instance, to place the sensor when the patient is called to the OR rather than 1-2 hours before the start of the anesthetic care.

In summary, recent clinical trials have documented the multiple clinical advantages of intraoperative quantitative monitoring to guide the administration and reversal of NMBAs. For the optimal use of quantitative devices, baseline data obtained before the administration of an NMBA are needed. However, the time it takes to place the sensor in the OR may impact efficiency or even theoretically patient outcomes by prolonging the time from anesthetic induction until the administration of a NMBA and endotracheal intubation. Preoperative placement of the sensor may be feasible in older pediatric patients; alternative initiatives are needed for younger patients to ensure optimal sensor functioning after arrival to the OR.

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Conflicts of interest

There are no conflicts of interest.

References

1. Brull SJ, Kopman AF. Current status of neuromuscular reversal and monitoring: Challenges and opportunities. Anesthesiology 2017;126:173-90.
2. Viby-Mogensen J, Claudius C. Evidence-based management of neuromuscular block. Anesth Analg 2010;111:1-2.

3. Naguib M, Brull SJ, Johnson KB. Conceptual and technical insights into the basis of neuromuscular monitoring. Anaesthesia 2017;72(Suppl 1):16-37.
4. Bowdle A, Michaelsen K. Quantitative twitch monitoring: What works best and how do we know? Anesthesiology 2021;135:558-61.
5. Murphy GS. Neuromuscular monitoring in the perioperative period. Anesth Analg 2018;126:464-8.
6. Todd MM, Hindman BJ, King BJ. The implementation of quantitative electromyographic neuromuscular monitoring in an academic anesthesia department. Anesth Analg 2014;119:323-31.
7. Owusu-Bediako K, Munch R, Mathias J, Tobias JD. Feasibility of intraoperative quantitative neuromuscular blockade monitoring in children using electromyography. Saudi J Anaesth 2022;16;412-8.
8. Kalsotra S, Rice-Weimer J, Tobias JD. Intraoperative electromyographic monitoring in children using a novel pediatric sensor. Saudi J Anaesth 2023;17:378-82.
9. Renew JR, Hex K, Johnson P, Lovett P, Pence R. Ease of application of various neuromuscular devices for routine monitoring. Anesth Analg 2021;132:1421-8.
10. Faulk DJ, Austin TM, Thomas JJ, Strupp K, Macrae AW, Yaster M. A survey of the Society for Pediatric Anesthesia on the use, monitoring, and antagonism of neuromuscular blockade. Anesth Analg 2021;132:1518-26.
11. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap) – A metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inform 2009;42:377-81.
12. Harris PA, Taylor R, Minor BL, Elliott V, Fernandez M, O'Neal L, *et al*.; REDCap Consortium. The REDCap consortium: Building an international community of software platform partners. J Biomed Inform 2019;95:103208.
13. Thilen SR, Hansen BE, Ramaiah R, Kent CD, Treggiari MM, Bhananker SM. Intraoperative neuromuscular monitoring site and residual paralysis. Anesthesiology 2012;117:964-72.
14. Cammu G, De Witte J, De VeylderJ, Byttebier G, Vandeput D, Foubert L, *et al*. Postoperative residual paralysis in outpatients versus inpatients. Anesth Analg 2006;102:426-9.