IMPLEMENTATION OF AN INTRAOPERATIVE COGNITIVE AID TO GUIDE NEUROMUSCULAR BLOCKADE MONITORING

by

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ABSTRACT

KEVIN STOVALL. Implementation of an Intraoperative Cognitive Aid to Guide Neuromuscular Blockade Monitoring
(Under the direction of DR. STEPHANIE WOODS)

Residual neuromuscular blockade (rNMB) following general anesthesia can impair pulmonary mechanics and place patients at an increased risk to develop postoperative pulmonary complications (PPCs) (Saagar et al., 2019). PPCs are associated with increased readmission rate, hospital length of stay and overall morbidity and mortality (Kirmeier et al., 2019). Current literature suggests that clinicians play a pivotal role in the reduction of rNMB through the accurate assessment and interpretation of neuromuscular blockade with a peripheral nerve stimulator (PNS) (Thilen & Bhananker, 2016). For this project, a survey was distributed to anesthesia providers at a level one trauma center. Nine questions regarding neuromuscular blockade monitoring were included; two questions assessed current practice and seven questions assessed literature-based knowledge. The survey results revealed that while some content areas reflected up-to-date practice and knowledge by the practitioners, others did not align with current literature. For example, only 12.9% of survey participants correctly identified the most important and reliable use of the train-of-four count (TOFC), the most commonly used mode of the PNS. The identified areas of educational needs were identified via the survey and included on a cognitive aid to be used as an intra-operative reference tool. The cognitive aid was placed in operating rooms (ORs) throughout the facility in easily accessible areas on or near the anesthesia machine. This quality improvement (QI) project recommends continued evaluation and analysis of current practice trends as new literature and management modalities evolve.

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DEDICATION

This project is dedicated to all of those who have supported me throughout my academic career. Specifically, I want to dedicate this project to my fiancé, Abby, who has loved and supported me throughout this entire process—I could not have done it without you. I would also like to dedicate this project to my parents, who have given me the inspiration, support and strength to get through this difficult journey. Lastly, I want to dedicate this project to my dog, Archie, who's loving and playful energy has helped me through some of my most difficult and stressful days. Words cannot describe my appreciation for you all—thank you!

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LIST OF ABBREVIATIONS

CRNA	Certified Registered Nurse Anesthetist
DBS	double-burst stimulation
DNP	Doctor of Nursing Practice
Hz	hertz
IHI	Institute for Healthcare Quality Improvement
mA	milliamperes
MD	Medical Doctor
MSN	Master of Science in Nursing
NDMR	non-depolarizing muscle relaxant
NMB	neuromuscular blockade
NMJ	neuromuscular junction
OR	operating room
PDSA	plan-do-study-act
PNS	peripheral nerve stimulator
PPC	postoperative pulmonary complications
PTC	post-tetanic count
QI	quality improvement
QR	quick-response
RCT	randomized-control trial
rNMB	residual neuromuscular blockade
SRNA	Student Registered Nurse Anesthetist

TOF	train-of-four
TOFC	train-of-four count
TOFR	train-of-four ratio

Section I: Introduction

Background

Intraoperative muscle paralysis is common practice to optimize surgical exposure, facilitate tracheal intubation, and control patients' ventilation. The incidence of residual neuromuscular blockade (rNMB) following general anesthesia remains as high as 60% despite technological advancements in neuromuscular blockade (NMB) monitoring modalities and the introduction of novel pharmacologic reversal agents (Saager et al., 2019). Multiple studies cite an association between the pulmonary function impairment attributed to residual neuromuscular blockade and increased critical postoperative pulmonary complications (PPCs) (Kheterpal et al., 2020; Rudolph et al., 2018; Leslie et al., 2021; Saager et al., 2019). Current literature reveals that traditional, subjective assessment of clinical signs such as grip strength, tongue protrusion, and ability to sustain a five-second head lift are unreliable indicators of recovery of the protective reflexes needed to maintain a patent airway (Nagelhout, 2018). Reliance on these clinical indicators of recovery can underestimate the depth of NMB, leading to an insufficient neuromuscular reversal dose. Anesthesia providers must exercise vigilance to attenuate the incidence of residual paralysis and the subsequent negative sequelae. Proper monitoring of neuromuscular depth, identification of patients at high risk for developing rNMB and appropriate dosing of pharmacologic reversal agents are essential elements of competent clinical practice.

Monitoring the neuromuscular junction is often performed using a peripheral nerve stimulator (PNS), also clinically referred to as a train-of-four (TOF) monitor. Anesthesia providers must account for electrode location, the quality of twitches elicited, and the current applied to interpret TOF findings accurately. For example, TOF monitoring at the ulnar nerve has a closer correlation with pharyngeal muscle recovery than monitoring at the facial nerve

(Murphy, 2018). When used correctly, the TOF gives the anesthesia provider valuable information regarding NMB depth to guide prudent reversal (Thilen & Bhananker, 2016). The train-of-four ratio (TOFR) compares the amplitude of the fourth twitch to the amplitude of the first twitch to produce a numerical value that correlates with recovery at the neuromuscular junction (NMJ). Understanding the strengths and limitations of qualitative TOF monitoring is a foundational skill in managing NMB.

Problem Statement

Residual paralysis following general surgery is a significant risk factor implicated in the development of major postoperative pulmonary complications PPCs. Kirmeier et al. (2019) found that patients demonstrating a TOFR less than 0.9 exhibited impaired respiratory control during hypoxia, increased propensity for airway obstruction, and higher aspiration rates. PPCs such as respiratory failure, the need for reintubation within 24 hours, and pneumonia are associated with pathophysiologic, financial and emotional burdens by increasing hospital length of stay, the number of readmissions, and overall morbidity and mortality. According to a multicenter, prospective study conducted by Kirmeier et al. (2019), approximately five percent of adult patients undergoing non-cardiac surgery will experience a major PPC, resulting in increased mortality and $100,000 in additional costs per occurrence. Reducing the incidence of rNMB is a key, modifiable risk factor to improve postoperative outcomes for patients and healthcare systems.

Several studies implicate considerable variation in provider reversal management and inter-individual pharmacologic variability as important influencers for rNMB (Ji et al., 2021; Murphy et al., 2018; Saager et al., 2019). A lack of standardization by anesthesia providers regarding electrode placement for accurate monitoring with a PNS and dosing of reversal agents according to the determined depth of neuromuscular paralysis are two such influences of rNMB.

Purpose

The aim of this quality improvement project is to identify current practice for NMB monitoring using the PNS at a level one trauma center with 46 fully functional operating rooms. This PNS project was part of a larger QI project that contains three distinct components: NMB monitoring with a PNS, reversal with neostigmine (Cornette, 2022), and reversal with sugammadex (Pleva, 2022). The goal of the larger QI project was to create a cognitive aid as an intraoperative reference guide for managing neuromuscular blockade. Current practice trends for NMB monitoring from this project were identified and analyzed in relation to best practices in current literature. Findings from the review of literature and current practice trends served to inform the PNS monitoring component and were included in the cognitive aid.

Clinical Question

In adult surgical patients requiring neuromuscular paralysis, how does best-practice evidence in the literature, compared to current knowledge and practice on PNS monitoring, inform management of neuromuscular blockade?

Section II: Literature Review

A literature review was conducted using the search terms, “neuromuscular blockade”, “residual paralysis”, “neuromuscular monitoring”, “postoperative pulmonary complications”, “general anesthesia” and “delayed emergence”. An extensive electronic search was completed using multiple databases, including PubMed, Science Direct, Cochrane Database of Systematic Reviews, and CINAHL Complete. Relevant, peer-reviewed articles and research published from 1985 through 2021 with full-text availability in the English language were included. Studies that included non-human subjects, patients less than 18 years of age, emergency and outpatient surgery were excluded

Peripheral Nerve Stimulation to Assess the Depth of Neuromuscular Blockade

Monitoring neuromuscular blockade is an essential component of anesthetic practice during surgery. Neuromuscular monitoring is most commonly performed using a peripheral nerve stimulator (Naguib et al., 2010), also clinically referred to as a train-of-four monitor. Anesthesia providers must consider several factors when using the PNS, including electrode location, the quality of twitches elicited, and the sequence applied. All of the components mentioned above are crucial to accurately interpret PNS findings and help guide the management of neuromuscular blockade (Murphy, 2018).

Qualitative vs. Quantitative Monitoring

To correctly and proficiently interpret the information provided by the PNS, anesthesia providers must understand and recognize the capabilities and limitations of the device. According to Brull & Kopman (2017), the peripheral nerve stimulator should be considered a simple medical device rather than a true monitor. The device delivers electrical impulses to a peripheral nerve that allows providers to assess the evoked response subjectively; the evaluation is based on a tactile or visual interpretation that often varies among providers (Brull & Kopman, 2017; Thilen & Bhananker, 2016).

Fade is used to quantify the difference in twitch height between the first and fourth twitch by a PNS in modes such as TOF and double-burst stimulation (DBS). Fade is represented numerically as a ratio from zero to one to quantify the degree of neuromuscular blockade. Several studies suggest that tracheal extubation should not be considered until a TOFR > 0.9 is achieved as it is traditionally considered the neuromuscular recovery threshold (Brull &

Kopman, 2017; Murphy, 2018). This recommendation is reiterated in international anesthesia practice guidelines written by Plaud et al. (2020). Blobner et al. (2020) conducted a large, 3150 patient multicenter observational study that found the TOFR requirement to be even higher, concluding that a ratio > 0.95 before extubation was associated with fewer postoperative complications than 0.9. These study results echoed the findings from a 211-hospital, 28-country observational study conducted by Kirmeier et al. (2019). However, past and current studies have shown that even experienced clinicians cannot reliably detect a TOFR greater than 0.4 without the use of a quantitative monitor (Brull & Silverman, 1993; Plaud et al., 2010; Viby-Mogensen et al., 1985). Moreover, clinical indicators thought to demonstrate readiness for extubation, such as the sustained five-second head lift, usually corresponds to a TOFR of 0.50 to 0.60 (Miller and Pardo, 2011). Therefore, current literature emphasizes that significant neuromuscular blockade may still be present when no fade is detected by the clinician (Murphy, 2018). In light of evolving research, a panel of clinical experts in neuromuscular blockade released a consensus statement that recommended the abandonment of qualitative NMB monitoring in favor of quantitative monitoring (Naguib et al., 2018). Alternatively, Thilen & Bhananker (2016) argue that when used correctly and within its limits, the PNS can help decrease the incidence and severity of residual neuromuscular blockade.

PNS Modes

Train-of-four (TOF)

The PNS has several modes and stimulation patterns that provide the clinician with different information for interpretation. The TOF is the most commonly used (Murphy, 2018; Naguib et al., 2010). In the TOF mode, four stimuli are provided 0.5 seconds apart, at a frequency of two hertz (Hz) each. The current applied, measured in milliamperes (mA), during this time should be 10-15% greater than the stimulus required to elicit a maximal muscle fiber contraction. In most surgical patients, a stimulus of 50-60 mA is sufficient (Murphy, 2018). The number of responses to the four stimuli is termed the train-of-four count (TOFC) and is used to determine the depth of neuromuscular blockade. However, even with a TOFC=4, 70% of receptors can still be occupied by a non-depolarizing muscle relaxant (NDMR) (Nagelhout, 2018). A prospective observational study containing 75 participants compared the TOFC assessed subjectively by providers to the TOFC obtained by an objective accelerometry watch. The study found that the subjective and objective methods reported the same TOFC in only 56% of the observations (Bhananker et al., 2015). Moreover, when the two assessment methods were not in agreement, 96% of the subjective reporting's were found to overestimate the TOFC, increasing the likelihood of NMB mismanagement (Bhananker et al., 2015). However, in a later publication, several of the same authors included in the study above concluded that the TOFC can be used to help decrease residual paralysis, primarily when used to guide the timing of reversal (Thilen & Bhananker, 2016).

Double Burst Stimulation (DBS)

Based on the research findings that clinicians are unable to accurately determine a TOFR >0.4, the DBS pattern was introduced into clinical practice to facilitate the subjective assessment of fade (Brull & Kopman, 2017). The DBS pattern uses two 50 Hz stimuli separated by a 750-millisecond interval and has been shown to slightly increase the threshold for subjective assessment of fade, as compared to the TOF (Murphy, 2018). A small, 32 participant observational study conducted by Capron et al. (2006) found that the DBS mode increased the provider's ability to accurately detect fade up to a ratio of 0.6-0.7. Although the small sample size limited the reliability of the study, their findings were reinforced by a consensus statement released by the International Anesthesia Research Society in 2018 (Naguib et al., 2018). Despite discovering that the DBS technique demonstrated an increased ability to detect residual paralysis, the inability to discern a ratio >0.6 still leaves room for undetectable neuromuscular blockade (Brull & Kopman, 2017; Capron et al., 2006).

Post-Tetanic Potentiation

Tetanic stimulation applies high frequency, 50 Hz impulses for a continuous five seconds. The constant stimulation increases the acetylcholine at the neuromuscular junction, resulting in a single, sustained contraction. If fade is present, the clinician can observe it during the five-second contraction. However, studies have shown that tetanic stimulation is the least sensitive method to detect fade subjectively (Capron et al., 2006). Alternatively, a post-tetanic count (PTC) can be used to assess deep neuromuscular blockade when the traditional TOF evokes no response (Murphy, 2018). The high-frequency tetanic stimulation causes an increased release of acetylcholine, amplifying the strength of subsequent muscle contractions. According to Brull & Kopman (2017), when the PTC is six to eight, neuromuscular recovery to a TOFC of 1 is likely imminent from an intermediate-acting NDMR. Similarly, Murphy (2018) states that a PTC of 10-12 typically corresponds to a TOFC of 1. Providers must exercise caution when performing tetanic stimulation due to a phenomenon known as post-tetanic potentiation, in which a stimulation within two to five minutes after tetanic stimulation amplifies the subsequent TOFC, underestimating the degree of neuromuscular blockade (Brull & Kopman, 2017; Ehrenwerth et al., 2013).

Electrode Location

The literature describes that different muscle groups have various sensitivities to NDMRs, and, therefore, a different time course for onset and recovery of muscle paralysis.

(Brull & Kopman, 2017; Donati, 2012; Murphy, 2018). According to Murphy (2018), the two most common locations monitored by anesthesia providers are the adductor pollicis muscle (via the ulnar nerve) and orbicularis oculi/corrugator supercilii muscles (via the facial nerve). Research has shown that the facial nerve and orbicularis oculi/corrugator supercilii muscles are significantly more resistant to the effects of NDMRs, and therefore recover faster than the adductor pollicis (Naguib et al., 2018). The adductor pollicis muscle closely reflects the sensitivity and recovery time course of the pharyngeal muscles and, as such, represents a critical indicator of a patient's ability to protect and maintain the airway (Brull & Kopman, 2017). A prospective cohort study of 180 patients conducted by Thilen et al. (2012) found that patients with qualitative TOF monitoring at the eye muscles had a fivefold higher risk for rNMB than patients monitored at the adductor pollicis. As a result, researchers suggest that if monitoring must be done at an alternative location, such as the facial nerve, the electrodes should be switched back to the ulnar nerve at the end of the procedure (Donati, 2012; Murphy, 2018).

A common issue reported in the literature is improper placement of the electrodes at their respective monitoring sites (Murphy, 2018). In their publications, clinical experts emphasized the importance of avoiding the placement of electrodes directly on the muscles as it may cause direct muscle stimulation and underestimate the depth of paralysis (Murphy, 2018; Thilen & Bhananker, 2016). The recommended electrode placement for precise ulnar nerve monitoring consists of a negative electrode (black) placed two centimeters proximal to the wrist crease with a positive electrode (red) placed four centimeters directly above it (Barash, 2017). This positioning helps ensure maximal neuronal stimulation and muscular response (Brull & Silverman, 1995). When facial nerve monitoring must be used, the neuromuscular monitoring consensus statement released in 2018 suggests electrode placement near the stylomastoid foramen or just anterior to the ear lobe to elicit contraction of the orbicularis oculi or corrugator supercilii muscles (Naguib et al., 2018). However, Barash (2017) argues that even with optimal electrode location, muscle responses can still be evoked due to direct stimulation.

Timing of Assessment

According to Thilen & Bhananker (2016), the most important role of the PNS is to help guide the timing of pharmacological management and NMB reversal. First, the authors discussed the importance of early PNS monitoring, starting after anesthetic induction but before NDMRs are administered to facilitate confirmation of electrode placement and PNS functioning (Thilen & Bhananker, 2016). Moreover, the publication states that using the PNS can help identify patients who have prolonged paralysis from a usual dose of NDMR and subsequently guide incremental dosing (Thilen & Bhananker, 2016).

Traditionally, many providers were taught that NMB reversal with neostigmine is acceptable when one to two twitches in the TOFC are present (Thilen & Bhananker, 2016). However, several studies and publications have found this practice to be inadequate and recommend providers wait until a TOFC of four is achieved (Kim et al., 2004; Kirkegaard et al., 2002; Murphy & Kopman, 2016; Plaud et al., 2010). In a 64 patient randomized control trial (RCT), Kirkegarrd et al. (2002) found that following cisatracurium induced paralysis, 93% of patients with a TOFC of four achieved a TOFR $\geq$ 0.7 within 10 minutes of neostigmine reversal, while only 50% of patients with a TOFC of one achieved a TOFR $\geq$ 0.7. However, it should be noted that the study recognized that current literature now recommends a higher TOFR to ensure adequate NMB recovery and found that the majority of patients in the study did not achieve a TOFR $\geq$ 0.9 within 10 minutes of neostigmine administration, regardless of TOFC before reversal (Kirkegaard et al., 2002). Similar results have been reported for other commonly used

NDMRs. In a more extensive, 160 patient RCT, Kim et al. (2004) found that following rocuronium-induced paralysis, neostigmine reversal with a TOFC of four resulted in a TOFR ≥ 0.9 in 55% of patients within 10 minutes and 95% of patients within 15 minutes. Moreover, 40% of patients reversed with a TOFC of one failed to achieve a TOFR ≥0.9 within 30 minutes (Kim et al., 2002). The authors recognized that their findings were only applicable to the specific NDMR used in their respective trials due to different pharmacologic profiles between NDMRs. However, both Kim et al. (2004) and Kirkegaard et al. (2002) found an increased reversal efficacy and completeness when neostigmine was given with a TOFC of four.

Summary of Findings

Residual neuromuscular blockade and subsequent adverse respiratory events prevent patients' optimal postoperative recovery. Anesthesia providers are responsible for inducing, maintaining, and adequately reversing muscle paralysis. The first step in reversal is using and correctly interpreting an NMB monitoring device. The PNS is widely considered a qualitative monitoring device, relying on subjective interpretation (Brull & Kopman, 2017). However, when used correctly and within its limits, researchers have found that the PNS can help decrease the incidence and severity of residual neuromuscular blockade (Thilen & Bhananker, 2016). Regardless of the mode used, studies have found that clinicians can accurately detect a TOFR up to 0.6, which is far below full NMB recovery (Brull & Kopman, 2017; Capron et al., 2006). The PNS should be used to monitor the adductor pollicis as it more closely reflects the recovery of the upper airway muscles (Brull & Kopman, 2017; Naguib et al., 2018). Lastly, the reversal should be held until TOFC of four is reached, as studies have shown it increases the likelihood of complete NMB reversal (Kim et al., 2004; Kirkegaard et al., 2002).

Theoretical Framework

The Plan, Do, Study, Act (PDSA) model was used in this quality improvement project focused on PNS monitoring to help guide NMB management. The PDSA model is used extensively under the Institute for Healthcare Quality Improvement (IHI) to implement change or improve existing processes to improve patient care (McBride et al., 2018). The cyclical nature of the PDSA components emphasizes continual analysis and refinement of changes.

The "plan" was to complete a thorough review of the literature and to create a survey to assess current knowledge and practice habits among anesthesia providers using a PNS monitoring device for the management neuromuscular blockade. The "do" was distributing a survey via SurveyMonkey to all anesthesia providers staffed at a large, urban trauma center. The survey included nine questions regarding NMB monitoring: two current practice questions and seven knowledge based questions. As NMB monitoring is part of a larger, three component project, the total survey included 28 questions: three demographic questions, eight current practice questions and seventeen knowledge based questions. The NMB monitoring questions included eight true-or-false questions, and one multiple-choice question. A quick-response (QR) code with the link to the survey were placed in 22 ORs and in the anesthesia break room. Successful implementation of the plan required collaboration from committee members to promote meaningful participation in the survey.

The "study" component analyzed the survey responses to identify trends surrounding NMB monitoring and reversal among anesthesia providers. The results were collected in SurveyMonkey and exported for detailed analysis and review. Individual data points were aggregated according to subject content to determine common themes for improvement in clinical practice. The evidence synthesis plus model helped integrate evidence-based practice guidelines focused on areas of needed improvement identified in the survey findings into a concise cognitive aid. The final "act" component of the PDSA model was to formulate a cognitive aid. The cognitive aid was placed on the anesthesia machine throughout the operating rooms for efficient intraoperative reference.

Section III: Methodology

Project Design

This project followed the evidence synthesis plus project model and served as the first steps in translating research into practice related to neuromuscular blockade management in anesthesia (Bonnell & Smith, 2018). The project included a comprehensive review and synthesis of current literature and analysis of survey data of current clinical practice for monitoring neuromuscular blockade. After integrating knowledge gained from the literature review and survey findings, evidence-based guidelines were delivered to anesthesia providers through an easily accessible cognitive aid to guide best practices for neuromuscular blockade management.

Setting

The survey was distributed to the anesthesia providers in a level one trauma center. The trauma center is also an academic medical center teaching hospital, providing residency training for more than 200 physicians in 15 specialties. Moreover, the institution is distinguished as a certified transplant center for heart, kidney, liver, and pancreas. The innovative technology used allows many surgical procedures to be performed using minimally-invasive laparoscopic or robotic surgical approaches. While these less-invasive approaches offer numerous benefits, including decreased pain and a shorter hospital stay, surgeons must rely upon precision to achieve successful outcomes (Barash et al., 2017). Such precision typically warrants the use of pharmacologic muscle relaxation to avoid inadvertent patient movement that could jeopardize damaging surrounding organs. Appropriate management and monitoring of neuromuscular blockade is integral to achieving optimal patient outcomes, as paralytic use is a common daily practice for anesthesia providers.

Subjects

This project utilized a convenience sampling method with all anesthesia staff receiving a survey related to current practices with neuromuscular blockade management. Student Registered Nurse Anesthetists (SRNAs) were excluded from participation. Based on the current staffing census, the potential population included 212 anesthesia providers—165 Certified Registered Nurse Anesthetists (CRNAs) and 47 Anesthesiologists. Varying demographics among anesthesia providers were anonymously assessed in the survey. Data obtained related to the sample population included academic degree held and years since completion of anesthesia training. The providers self-selected whether or not they completed the survey. As a result of the method chosen, the project's findings did not extend to the general population of anesthesia providers– only to those who participated in the QI project (Stratton, 2021).

Intervention

The survey findings aimed to identify current practice habits surrounding NMB monitoring with the PNS. The validity of the survey questions was determined according to approval from the appointed clinical expert and OR leadership. Once current practice habits were identified, trends and integrated evidence-based guidelines from the review of literature were used to inform the creation of a cognitive aid that served as an intraoperative reference to NMB management. Specifically, this component focused on NMB monitoring. As part of the larger project, the final cognitive aid included three central components of NMB management: qualitative monitoring using a PNS, pharmacological reversal of NMB using neostigmine and reversal of sugammadex. For the monitoring component of the project, the cognitive aid included written and pictorial instructions on electrode placement, strengths of the PNS as a NMB monitoring device and its' proper uses reported in literature. The cognitive aid was then placed in a clear, easy-to-access location on or near the anesthesia machine as an intraoperative reference tool.

Data Collection

Data was collected using a nine-item survey on NMB monitoring. This included two true or false current practice questions and seven multiple-choice knowledge based questions. Surveys were sent to CRNAs and Anesthesiologists using the SurveyMonkey platform. Anesthesia providers received an email reminder of the upcoming survey with detailed instructions on how to access the survey link via QR code. The QR code was posted in the anesthesia breakroom and on anesthesia machines in the operating room. QR codes were placed in ORs 1-8, 18, 19, 30-35 and 41-46. The respective rooms were selected because of their high volume of surgical cases requiring muscle paralysis. The survey's primary goal was to assess the management of neuromuscular blockade monitoring with the PNS among anesthesia providers. Subsequently, the data obtained was used to identify facility-specific education needs to inform the development of the cognitive aid.

Timeline for data collection

Data was collected following IRB approval from the institution and UNC Charlotte. Prior to distributing the survey, a brief description of the project was given during an anesthesia grand rounds meeting on July 14th, 2022. The period for data collection began with the survey distribution on August 29th, 2022. The survey remained open for completion for one month, from August 29th to September 29th, 2022. Reminders to complete the NMB survey were sent on September 21st, 2022, September 27th, 2022 and September 29th, 2022. Survey results were analyzed, along with findings from the synthesis of the literature, to initiate the development of the cognitive aid from September 29th to October 30th, 2022. The finalized and approved cognitive aid was implemented on throughout the operating rooms of the level one trauma center.

Data management and confidentiality of data

Survey responses were anonymous to ensure the confidentiality of the information gathered. Academic degree and years since completing anesthesia training were the only pieces of demographic information survey participants were asked to provide. Participants were asked to check a box if they consent for their responses to be reported in aggregate for analysis in the final project report. Data sharing during the project was strictly limited to members of the project committee.

Data Analysis and Evaluation

The success of the initial survey was measured by evaluating the responsiveness of anesthesia providers. The returned surveys identified areas with high training needs and were one measure of success in achieving the goal of creating a cognitive aid. The survey yielded a 36.3% return rate from providers.

Data analysis was completed with descriptive statistics of the nine-question survey given to anesthesia providers. The SurveyMonkey results were exported via Microsoft Excel and statistical analysis was completed with the assistance of a statistician. Each participants' responses were distributed utilizing a frequency-count table. This table provided the opportunity to review individual responses to specific survey questions providing an average response to questions about peripheral nerve stimulation (Bonnel & Smith., 2018). Logistic regression tested whether years of experience increased the odds of getting the knowledge questions correct.

A score of 80% was used to differentiate survey responses. Questions not meeting this benchmark within the sample were considered a focal point within the cognitive aid. After interpreting both the survey data and synthesizing the relevant literature, an educational cognitive aid detailing the best practices for TOF monitoring techniques was developed. This method is consistent with the evidence synthesis plus project model.

Section IV: Survey Results

Sample Characteristics

A total of 77 anesthesia providers participated in the survey, corresponding to an overall participation rate of 36.3%. The majority of participants were CRNAs (n=68); 83% of the CRNA respondents held a Master's degree (n=57), and 17% held a Doctor of Nursing Practice degree (n=11). Nine Physician Anesthesiologists also completed the survey (see figure 1). The years of experience varied among respondents as follows: 37 participants had <5 years of experience (48%), 14 respondents had 6 to 10 years of experience (18%), 15 participants had 11 to 20 years of experience (19%), and 11 respondents had >20 or more years of experience (14%) (see figure 2).

Figure 1

Degree held among participating anesthesia providers

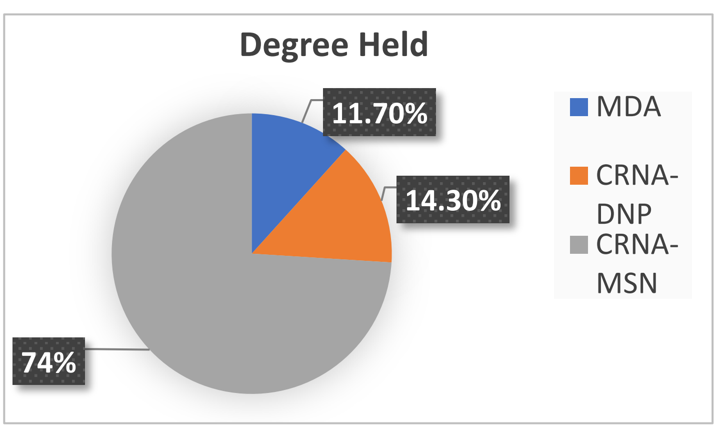
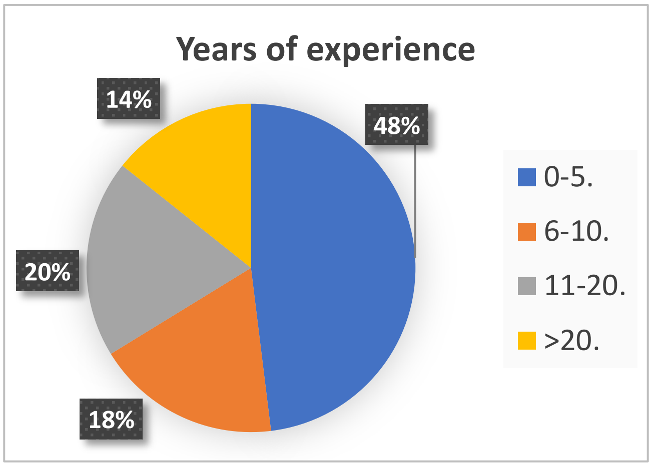


Figure 2

Years of experience among participating anesthesia providers



Survey Results

Table 1

NMB monitoring survey findings

Item	Descriptor/ Frequency	Percent Correct
When monitoring neuromuscular blockade depth at the facial nerve intraoperatively, I routinely move the peripheral nerve stimulator electrodes to the adductor pollicis before extubation.	True (n=18) False (n= 59)	n/a
When monitoring the facial nerve, I place the electrodes closest to the tragus and corner of the eye, directly above one another.	True (n=48) False (n=29)	n/a
Current literature recommends a train-of-four ratio of at least 0.80 to reduce the incidence of residual neuromuscular blockade.	True (n=57) **False (n=19)**	24.70%

When assessing a qualitative train-of-four ratio, current research shows that the majority of clinicians overestimate the value, resulting in underdosing pharmacologic reversal.	**True (n=74)** False (n=3)	96.10%
Seventy percent of the receptors at the nicotinic neuromuscular junction can still be occupied by a muscle relaxant with a train-of-four count of 4.	**True (n=74)** False (n=3)	96.10%
A patient's ability to sustain a 5-second head lift corresponds to a train of four ratio of 0.50-0.60	**True (n=34)** False (n=43)	44.20%
Following a 5-second tetanic stimulation, any subsequent stimulation(s) will be amplified for approximately 2-5 minutes, resulting in an underestimated degree of neuromuscular blockade.	**True (n=68)** False (n=9)	88.30%
Monitoring train-of-four at the facial nerve best indicates readiness of extubation as it most closely reflects recovery of the pharyngeal muscles, thereby decreasing the risk for upper airway obstruction and aspiration.	True (n=16) **False (n=60)**	77.90%
The train-of-four count is most beneficial to inform anesthesia providers about the:	a.Dosing of reversal agent (n=14) b.Time to spontaneous recovery (n=16) c.Depth of neuromuscular blockade (n=46) **d.Timing of reversal agent (n=10)**	12.99%

The frequencies for each item on the survey are reported in Table 1. The first two questions included in the survey assessed current practice and do not have a percent correct reported. However, only 23% (n=18) of respondents reported routinely moving the peripheral nerve stimulator electrodes to the adductor pollicis before extubation and nearly 38% (n=29) of respondents reported not placing the electrodes in the recommended location when monitoring the facial nerve.

The seven graded knowledge based questions report the percent correct to each question. 57% of the knowledge based questions were answered with at least 77% accuracy, and approximately 30% of the questions were answered with 96% accuracy. Questions regarding the TOFC were answered with lower accuracy. Approximately 25% of respondents correctly identified the TOFC needed to reduce the incidence of residual neuromuscular blockade, and 44.2% of respondents correctly identified the TOFC corresponding to the five-second head lift. Moreover, only 12.9% of survey respondents reported that the TOFC is most useful to guide the timing of the reversal agent. The lower scores on the TOFC content areas suggests that practitioners at the surveyed facility would benefit from up-to-date information regarding the TOFC on the cognitive aid.

Each of the demographic variables included on the survey were examined for any association with each NMB monitoring questions on the survey. The demographic information collected included degree held (MD, CRNA-DNP, CRNA-MSN) and years of experience. Results of the logistic regression indicated a significant association between years of experience and the correct identification of the recommended TOFR needed to reduce residual neuromuscular blockade. This finding indicates that more years of experience reduced the correct identification of the recommended TOFR (*odds ratio=0.55, p=.041*). A possible explanation for this finding is that the recommended TOFR to reduce residual neuromuscular blockade has continued to increase as new evidence has emerged. There were no other significant associations with the remaining questions on the survey.

Section V: Discussion

Implications for Practice

The findings from both the current practice and knowledge assessment revealed significant implications for practice for NMB monitoring. Thilen et al. (2012) found that patients with qualitative TOF monitoring at the eye muscles had a fivefold higher risk for rNMB than patients monitored at the adductor pollicis. As a result, researchers suggest that if monitoring is done at an alternative location, the electrodes should be switched back to monitor the adductor pollicus at the end of the procedure (Donati, 2012; Murphy, 2018). However, the current practice survey revealed that only 23% (n=18) of respondents at the institution switched the monitoring site to the adductor pollicus. Moreover, the survey revealed that nearly 38% (n=29) of respondents did not routinely place the electrodes in the optimal location when monitoring the facial nerve. Both findings suggests that a large percentage of current practice among respondents regarding PNS monitoring location is not in line with current literature and best practice. As a result of the current practice findings, optimal electrode location was included on the cognitive aid.

Although the PNS is widely considered a qualitative monitor and requires subject interpretation of the TOFR, the use of the PNS can help decrease the prevalence of rNMB among patients (Brull & Kopman, 2017; Thilen & Bhananker, 2016). However, practitioners must have a strong understanding of the TOFR and limitations of subjective monitoring. The survey revealed that only 24.70% (n=19) of respondents correctly identified the recommended TOFR to best reduce the incidence of rNMB. Moreover, only 44.20% (n=34) of respondents correctly correlated the clinical indicator of a sustained five-second head lift with the correct TOFR. The findings suggest a gap in knowledge surrounding current literature for recovery of NMB based on the TOFR.

Respondents of the survey demonstrated a strong knowledge base surrounding modes of the PNS, provider utilization and interpretation of findings. Almost 90 % (n=68; 88.3%) of respondents answered correctly when asked about post-tetanic potentiation and its implications. Over 90% (n=74; 96.1%) of respondents answered correctly regarding the tendency of clinicians to overestimate the TOFR and its associated underdosing of reversal agent. And, almost 80% of the respondents (n=60; 77.9%) recognized that the facial nerve is not the ideal monitoring location to predict readiness for extubation as it does not indicate recovery of pharyngeal muscles. The majority of survey responses for these topics were found to be consistent with current literature and recommendations. Therefore, these topics were not made a focal point on the cognitive aid.

Understanding the strengths and limitations of the PNS for NMB is essential to ensure proper and accurate use of the device (Thilen & Bhananker, 2016). Over 90% of respondents (n=74; 96.1%) recognized that 70% of the receptors at the nicotinic neuromuscular junction can be occupied by a muscle relaxant with a TOFC of four, which accurately describes a limitation of the PNS monitor as a NMB monitoring device. Given the high percentage of respondents that answered correctly, the receptor occupancy related to the TOFC was not included on the cognitive aid. However, only 12.99% (n=10) respondents correctly selected the most beneficial use of the TOFC: to help guide the timing of the reversal agent. The lack in knowledge surrounding the primary strength of the PNS indicates that respondents would benefit from additional information to help guide the use of the PNS monitor and therefore was included on the cognitive aid.

The information chosen to be included on the cognitive aid was a direct result of the survey findings and review of literature. In general, questions from the cognitive aid that less than 80% of respondents answered correctly were made a focal point on the cognitive aid. The cognitive aid included three content areas: correct electrode placement, the TOFR—including the recommended TOFR to reduce rNMB and TOFR correlation with clinical signs—and the most beneficial use of the PNS. These content areas correlate with questions one, three and nine of the PNS survey.

Strengths

One strength of the project was that the survey identified needs specific to the anesthesia providers at the surveyed group. Different facilities often have different devices or methods of monitoring—only including one anesthesia provider group situated in a major health system allowed analysis of providers with access to the same monitors, medications and resources. This helped to create a more tailored and applicable cognitive aid.

Additionally, due to the small sample size, data was quickly aggregated leading to implementation of the cognitive aid in a relatively short period of time. The survey was made available to the anesthesia providers via QR codes placed in the break rooms and on 22 anesthesia machines throughout the OR. This strategy intended promote participation by strategically placing the survey QR codes in areas of high foot traffic of anesthesia providers. Moreover, the project was introduced at an online grand-rounds meeting to the entire anesthesia staff. The meeting was followed by email reminders to participate in the survey. Lastly, the surveyed providers work at the same facility that the investigator completes clinical rotations—this allowed the opportunity to promote participation in the survey. The introduction, follow-up emails and student-facility association were all strengths of the project and helped increase participation.

Limitations

One major limitation is that the findings of the project lack relevance to other anesthesia provider groups and healthcare facilities. Although the tailored approach helped increase the usefulness and relevance of the cognitive aid for the anesthesia providers at the identified facility, it also reduced the relevance and reach to other healthcare facilities. There was also a lack of survey participation with a final participation rate of 36.3% among anesthesia providers. This was well below the goal of 60% participation.

While the survey questions were meant for ease of participation, the item style was not always conducive to collecting a fuller picture of provider knowledge. The true or false style questions introduced a limitation. For example, the survey successfully identified respondents who answered correctly regarding the facial nerve not being the ideal monitoring location, but did not assess whether or not the respondents could identify the adductor pollicus as the ideal location. Additionally, it was possible for anesthesia providers to take the survey more than one time if done from a separate device. As a result of the anonymity of the surveys, there was no way to determine if survey respondents completed the survey multiple times. Finally, the information included on the cognitive aid was based on results from the survey data; however, additional validation of the survey is needed.

Recommendations

There are both short and long term recommendations based on the findings from this project. One recommendation is to obtain more expert input to validate the survey and more evenly balance the number of true or false questions and multiple choice questions. Adding more multiple choice questions also comes with a requisite increase in time to complete the survey; both need balanced. Additionally, questions in which respondents answered at least 90%

correctly should be re-evaluated. Lastly, it is recommended the survey be distributed while no other surveys are being sent to anesthesia providers.

In the weeks to months following the cognitive aid distribution, the investigator recommends collecting provider feedback regarding the cognitive aid. This would include feedback on usability, accessibility and resourcefulness. As new literature, NMB management modalities and facility guidelines evolve, continued evaluation and analysis of current practice trends is recommended. This will help inform and promote practice consistent with current literature and best practice.

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Appendix A: Neuromuscular Blockade Management Survey

Current Practice

1. When monitoring neuromuscular blockade depth at the facial nerve intraoperatively, I routinely move the peripheral nerve stimulator electrodes to the adductor pollicis before extubation.
    1. True
    2. False
2. When monitoring the facial nerve, I place the electrodes closest to the tragus and corner of the eye, directly above one another.
    1. True
    2. False

Current Literature

1. Current literature recommends a train-of-four ratio of at least 0.8 to reduce the incidence of residual neuromuscular blockade.
    1. True
    2. **False**
2. When assessing a qualitative train-of-four ratio, current research shows that the majority of clinicians overestimate the value, resulting in underdosing pharmacologic reversal.
    1. **True**
    2. False
3. Seventy percent of the receptors at the nicotinic neuromuscular junction can still be occupied by a muscle relaxant with a train-of-four count of 4.
    1. **True**
    2. False
4. A patient's ability to sustain a 5-second head lift corresponds to a train of four ratio of 0.50-0.60.
    1. **True**
    2. False
5. Following a 5-second tetanic stimulation, any subsequent stimulation(s) will be amplified for approximately 2-5 minutes, resulting in an underestimated degree of neuromuscular blockade.
    1. **True**
    2. False
6. Monitoring train-of-four at the facial nerve best indicates readiness of extubation as it most closely reflects recovery of the pharyngeal muscles, thereby decreasing the risk for upper airway obstruction and aspiration.
    1. True
    2. **False**
7. The train-of-four count is most beneficial to inform anesthesia providers about the:
    1. Dosing of reversal agent
    2. **Timing of reversal agent**
    3. Depth of neuromuscular block
    4. Time to spontaneous recovery

Appendix B: NMB Monitoring Survey Findings

Item	Descriptor/ Frequency	Percent Correct
When monitoring neuromuscular blockade depth at the facial nerve intraoperatively, I routinely move the peripheral nerve stimulator electrodes to the adductor pollicis before extubation.	True (n=18) False (n= 59)	n/a
When monitoring the facial nerve, I place the electrodes closest to the tragus and corner of the eye, directly above one another.	True (n=48) False (n=29)	n/a
Current literature recommends a train-of-four ratio of at least 0.80 to reduce the incidence of residual neuromuscular blockade.	True (n=57) **False (n=19)**	24.70%
When assessing a qualitative train-of-four ratio, current research shows that the majority of clinicians overestimate the value, resulting in underdosing pharmacologic reversal.	**True (n=74)** False (n=3)	96.10%
Seventy percent of the receptors at the nicotinic neuromuscular junction can still be occupied by a muscle relaxant with a train-of-four count of 4.	**True (n=74)** False (n=3)	96.10%
A patient's ability to sustain a 5-second head lift corresponds to a train of four ratio of 0.50-0.60	**True (n=34)** False (n=43)	44.20%
Following a 5-second tetanic stimulation, any subsequent stimulation(s) will be amplified for approximately 2-5 minutes, resulting in an underestimated degree of neuromuscular blockade.	**True (n=68)** False (n=9)	88.30%
Monitoring train-of-four at the facial nerve best indicates readiness of extubation as it most closely reflects recovery of the pharyngeal muscles, thereby decreasing the risk for upper airway obstruction and aspiration.	True (n=16) **False (n=60)**	77.90%
The train-of-four count is most beneficial to inform anesthesia providers about the:	a.Dosing of reversal agent (n=14) b.Time to spontaneous recovery (n=16) c.Depth of neuromuscular blockade (n=46) **d.Timing of reversal agent (n=10)**	12.99%

Appendix C: Survey Demographic Figures