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Guidelines for Intraoperative Use of Quantitative Neuromuscular Monitoring

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Final Scholarly Project: Guidelines for Intraoperative Use of Quantitative Neuromuscular Monitoring

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We have no conflicts of interest to disclose.

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Abstract

Chemical paralysis with neuromuscular blocking agents is common practice in anesthesia. Adequate reversal of these medications is essential for postoperative recovery and return to physiologic baseline. Inadequate reversal may lead to residual paralysis and respiratory complications such as hypoxemia, upper airway obstruction, atelectasis, and pneumonia. Quantitative neuromuscular monitoring was introduced as an objective measure of adequate recovery from neuromuscular blockade. The American Society of Anesthesiologists recommends utilizing quantitative neuromuscular monitoring before tracheal extubation in their 2023 practice guidelines, as the research involving quantitative neuromuscular monitoring shows a reduction in postoperative residual paralysis rates and adverse respiratory complications postoperatively. In this study, the project team will collect data on the target facility's baseline postoperative residual paralysis rates. During a trial implementation phase, the anesthesia staff will implement the proposed guidelines, and additional data will be collected on postoperative residual paralysis rates following guideline implementation. The data will be compared, and the project team anticipates a statistically significant reduction in the overall incidence of postoperative residual paralysis using quantitative neuromuscular monitoring. If the desired outcomes are unmet, the team will investigate potential causes and adjust the guidelines accordingly.

Keywords: quantitative neuromuscular monitoring, qualitative neuromuscular monitoring, postoperative residual paralysis

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Problem Identification

Clinical Problem

Pharmacologic paralysis using neuromuscular blocking agents (NMBAs) occurs frequently in invasive procedures requiring anesthesia. The reversal of NMBAs ensures an appropriate return to baseline muscular activity after surgery. Reversal medications are administered to achieve adequate neuromuscular function to maintain a patent airway and sufficient alveolar ventilation necessary for physiologic homeostasis (Elisha et al., 2022). Alveolar ventilation is fundamental in preserving gas exchange and hemoglobin saturation to supply cells with the oxygen needed to function and rid them of metabolic byproducts (Hall & Hall, 2020). Therefore, tracheal extubation before sufficient neuromuscular recovery could be catastrophic to patients' recovery. To gauge readiness for neuromuscular blockade reversal, anesthetists traditionally rely on qualitative techniques to monitor block depth, including train-of-four (TOF) ratio and double-burst stimulation (DBS) (Elisha et al., 2022). However, research shows that when using qualitative techniques, patients continue to have inadequate neuromuscular blockade reversal, known as residual paralysis.

All surgical patients can develop residual paralysis after receiving an NMBA. However, specific patient populations are high-risk and prone to residual paralysis due to hepatic, renal, or underlying neuromuscular disease. Elisha et al. (2022) explain that NMBAs undergo altered metabolism and excretion in patients with renal and hepatic disease, leading to a prolonged duration of action. Additionally, patients who suffer from neuromuscular disorders, such as muscular dystrophy, myasthenia gravis, and multiple sclerosis, exhibit heightened sensitivity to

NMBAs, where the slightest dosage of these medications can result in profound paralysis (Romero & Joshi, 2013). Therefore, it is crucial to prioritize appropriate neuromuscular monitoring for high-risk populations due to their high susceptibility to the impact of NMBAs.

Residual paralysis poses a significant risk to patients upon tracheal extubation and transportation to the post-anesthesia care unit (PACU). Murphy and Brull (2010a) describe the potential adverse effects of residual paralysis as involving an increased risk for postoperative hypoxemia, upper airway obstruction, and pulmonary complications such as atelectasis or pneumonia. The above effects are critical to anesthesia as the anesthetist maintains the patients' airways throughout the perioperative period. With up to 64% of patients experiencing residual paralysis, it remains a persistent clinical problem after NMBA use and poses a considerable risk to patient health (Saager et al., 2019). To ensure patient safety, anesthesia providers are essential in implementing new practice techniques, such as quantitative neuromuscular monitoring, to mitigate the incidence of residual paralysis.

Although the current practice uses qualitative techniques for monitoring and reversing NMBA, new research indicates a need to utilize quantitative techniques for neuromuscular monitoring. Carvalho et al. (2020) report that quantitative monitoring methods result in less postoperative residual paralysis than qualitative methods. To further support the research, new recommendations released by the American Society of Anesthesiologists (ASA) state that quantitative monitoring should be employed over qualitative monitoring to reduce the incidence of postoperative residual paralysis (Thilen et al., 2023). Quantitative monitoring techniques should be incorporated to establish a minimum institutional standard of care and possibly increase patient safety.

Background

Qualitative Neuromuscular Monitoring

Anesthetists administering muscle relaxant medications need neuromuscular monitoring devices to assess the paralytic depth and the need for redosing. Neuromuscular monitoring devices elicit an electrical stimulus that causes a cascade of neuromuscular transmission, resulting in muscle contraction. Three clinical tests are traditionally used when monitoring neuromuscular function and residual paralysis: train-of-four, double-burst stimulation, and tetanus (Elisha et al., 2022). Each test can be used qualitatively and quantitatively to assess neuromuscular blockade intraoperatively.

The most common test when evaluating a patient's depth of paralysis is the train of four. Train-of-four applies four sequential stimuli to evoke muscle twitches; the number of twitches out of four denotes a certain percentage of muscular paralysis, with all four twitches present meaning the least paralysis (Elisha et al., 2022). However, even with four twitches present, 70% may still be blocked (Elisha et al., 2022). Train-of-four also allows the anesthetist to detect residual neuromuscular blockade through fade. A fade on the train-of-four measurement fails to maintain muscle contraction strength to repetitive nerve stimulation due to continued pharmacologic receptor blockade preventing additional neurotransmitter release (Elisha et al., 2022). This results in a robust initial twitch with a train-of-four but progressively weaker subsequent twitches. A comparison of the fourth twitch to the first, known as the train-of-four ratio, is frequently used to assess adequate recovery for tracheal extubation. A ratio of 0.9 is necessary to indicate appropriate recovery (Elisha et al., 2022). In traditional, qualitative neuromuscular monitoring, anesthesia providers rely on personal visual or tactile sensations to detect the presence or absence of twitches and fade.

The second clinical test is double-burst stimulation. Double-burst stimulation applies two stimuli to a nerve, resulting in muscle twitches, and is utilized in practice as a more accurate way to assess for residual paralysis (Elisha et al., 2022). Double-burst stimulation is thought to make it easier to detect residual paralysis through fade than train-of-four stimulation because the anesthetist compares back-to-back twitches. In contrast, train-of-four has two irrelevant twitches, the second and third, when assessing fade, and they can influence the anesthesia provider's observation of fade. The theory behind double-burst stimulation is to improve the efficacy of traditional, qualitative neuromuscular monitoring.

The final clinical test related to residual paralysis and fade is tetanus. The tetanus test applies an electrical stimulus for five seconds while the anesthetist monitors for a fully sustained contraction without fade, indicating a lack of substantial paralysis (Elisha et al., 2022). Each test discussed traditionally relies on the anesthetist to use personal judgment on the ratio between the twitches and the presence of fade. This exposes the patient to unnecessary risk. Evidence shows that anesthetists are often incorrect about their analysis of the train-of-four ratio when trying to detect residual paralysis (Murphy et al., 2008). Institutions can implement quantitative monitoring techniques to address this issue.

Quantitative Neuromuscular Monitoring

Standard quantitative neuromuscular monitoring methods include electromyography (EMG) and acceleromyography (AMG). EMG measures the number of action potentials generated by an electrical stimulus and generates an EMG signal amplitude proportional to the quantity; it is the closest direct evaluation of neuromuscular function (Longnecker et al., 2017). AMG measures the acceleration of a muscle contraction through piezoelectric crystals placed in a transducer attached to the extremity; the acceleration is directly proportional to the force of

contraction (Longnecker et al., 2017). Both EMG and AMG can be utilized to quantitatively assess neuromuscular paralysis depth and residual paralysis with train-of-four, train-of-four ratio, double-burst stimulation, and tetanus measurements.

Quantitative monitoring may be more efficacious for assessing neuromuscular blockade than traditional, qualitative monitoring. It is well-documented that qualitative visual and tactile assessment by anesthesia providers of the train-of-four ratio cannot distinguish between a ratio of 0.4 to 0.9, leading to residual paralysis post-operatively (Viby-Mogensen et al., 1985). In contrast, using EMG or AMG will provide an objective train-of-four ratio. Quantitative neuromuscular monitoring may enable providers to know the exact degree of residual paralysis and ensure adequate recovery before extubation.

Pharmacologic Reversal Agents

Neuromuscular monitoring, via qualitative and quantitative techniques, guides neuromuscular blocking agents' redosing and reversal agents' dosing. Reversal agents provide an expedited recovery from neuromuscular blockade pharmacologically rather than relying on the body’s metabolism and excretion for recovery. Standard reversal agents include a combination of neostigmine paired with glycopyrrolate or sugammadex as the sole reversal agent. The Anesthesia Patient Safety Foundation (APSF) released updated guidelines on the recommended reversal strategies to ensure optimal patient recovery. Chung et al. (2023) and the APSF recommend using sugammadex as the reversal agent for deep, moderate, and shallow neuromuscular blockade. Additionally, neostigmine is described as having similar efficacy as sugammadex with minimal blockade and can be used as a safe substitute in said situations (Chung et al., 2023). A summary of the APSF recommendations and reversal algorithm can be found in Appendix A.

Significance of the Problem to Nurse Anesthesia

Neuromuscular blocking agents (NMBAs) administered in the operating room are integral to the anesthesia repertoire and facilitate favorable surgical conditions. Anesthesia providers must ensure appropriate recovery from anesthesia and, specifically, NMBAs as they render the patient at risk for residual paralysis if not adequately reversed (Tsai et al., 2008). Potential adverse effects of residual paralysis in the postoperative period include postoperative hypoxemia, upper airway obstruction, delays meeting PACU discharge criteria and achieving discharge, prolonged ventilatory weaning, and increased risk of atelectasis and pneumonia (Murphy & Brull, 2010b). The adverse effects of residual paralysis can be life-threatening if unrecognized, and prompt intervention by an anesthetist is necessary.

To mitigate the incidence of residual paralysis and its adverse effects in PACU, anesthesia providers need to ensure adequate NMBA reversal, especially for high-risk patients. Anesthetists provide anesthesia to every type of patient, including those with coexisting liver, renal, or neuromuscular disease. In this population, the effect of many drugs, including NMBAs, can be challenging to predict and lead to unrecognized residual paralysis (Elisha et al., 2022). Implementing quantitative monitoring allows the anesthetist to objectively identify that the patient fully recovered from the neuromuscular blockade, reducing the risk of postoperative residual paralysis (Murphy & Brull, 2021). A vigilant anesthetist can recognize patients who are at high risk for residual paralysis and employ quantitative neuromuscular technology to reduce the incidence of residual paralysis and the adverse effects associated with it in the PACU.

Introducing quantitative monitoring can have several benefits for the patient and anesthesia staff. Thilen et al. (2023) explain that complete neuromuscular blockade reversal improves patient satisfaction through reduced PACU stays while decreasing postoperative

pulmonary complications. These benefits may also result in fewer anesthesia interventions in PACU, lessening the strain on anesthesia staff.

PICO(T) Question

The effects of anesthetic medications predispose patients to a reduced state of consciousness, and ensuring the patients' pharmacologic paralysis is fully reversed is necessary to contribute to fewer postoperative complications. To discover research supporting the implementation of evidence-based guidelines for quantitative neuromuscular monitoring, the following PICO question is used: In high-risk patients requiring the reversal of neuromuscular paralysis at the conclusion of general anesthesia **(P)**, how would the development and implementation of evidence-based guidelines related to quantitative monitoring of neuromuscular paralysis **(I)** compared to the traditional approach **(C)** affect the incidence of residual paralysis **(O)**?

Project Objectives

Implementing quantitative monitoring guidelines for reversing neuromuscular blocking agents may have many benefits. Notably, the implementation may reduce the incidence of postoperative residual paralysis and lead to fewer pulmonary complications in recovery (Carvalho et al., 2020). However, implementing new guidelines for patient care across healthcare systems poses significant barriers. The Doctor of Nursing Practice (DNP) project will address several obstacles, including developing comprehensive guidelines for staff reference, introducing strategies for monitoring the guideline's efficacy, and adjusting the guidelines to ensure advantageous outcomes.

The DNP project objectives seek to define the process of achieving the scholarly project's goals. The DNP project aims to implement evidence-based guidelines for quantitative

neuromuscular monitoring in the intraoperative period. To develop said guidelines, a literature search and synthesis were conducted to culminate research supporting positive patient outcomes while using quantitative neuromuscular monitoring instead of traditional qualitative neuromuscular monitoring. Additionally, measuring the effectiveness of quantitative neuromuscular monitoring and adjusting the guidelines to promote desirable patient outcomes will be accomplished in the project. To achieve the intent of the doctoral project, the objectives are as follows:

1. Develop evidence-based practice guidelines for quantitative neuromuscular monitoring following neuromuscular blocking agent administration.
2. Develop a comprehensive plan to implement quantitative neuromuscular monitoring.
3. Develop a comprehensive plan to monitor and measure quantitative neuromuscular monitoring use and effectiveness.
4. Develop a comprehensive plan to adjust the guidelines if the outcomes are less than desirable.

Review of Literature

Literature Search Strategy

Search Terms

The literature search was conducted utilizing a PICO question developed by the DNP student and several experts in the field of study. Critical components of a PICO question, including population, intervention, comparison, and outcomes, drive the literature search process and filter the overabundance of information down to relevant articles. Within the literature search, specific terms were used to produce relevant data, including quantitative monitoring, qualitative monitoring, neuromuscular monitoring, acceleromyography, and residual paralysis.

Alongside the key phrases, several Boolean operators, such as “and” and “or,” were employed to analyze the data further.

Databases

The literature search comprised a multitude of databases with the intent of revealing applicable evidence related to the abovementioned topic. Ultimately, Cochran Library, CINAHL (EBSCO), and PubMed were the databases utilized. The database searches produced a meta-analysis, several randomized controlled trials, and a quasi-experimental design. In conjunction with the database results, several articles were obtained from the updated 2023 American Society of Anesthesiologists (ASA) Practice Guidelines for Monitoring and Antagonism of Neuromuscular Blockade. Inclusion criteria for relevant articles included a timeline (2005-present), peer-reviewed, full-text available, and written in English. Articles excluded from the results consisted of the following criteria: not peer-reviewed, not written in English, full-text unavailable, or did not relate to the stated PICO interventions or outcomes.

Literature Synthesis

The literature review includes six articles supporting the integration of quantitative monitoring in the operating room to reduce the risk of postoperative residual paralysis. Of the six articles, one was a level I evidence meta-analysis of 40 years of literature, three were level II randomized control trials, one was a level III quasi-experimental study, and one was a level IV retrospective cohort study. After a review of the selected literature, the author analyzed the articles measuring the incidence of residual paralysis when using quantitative monitoring compared to the “traditional approach.”

The traditional approach to neuromuscular monitoring in the operating room to gauge readiness for tracheal extubation refers to qualitative techniques that often include no monitoring

with spontaneous breathing as the indicator of neuromuscular recovery, peripheral nerve stimulation (PNS) with tactile or visual observation of TOF and TOFR without fade, and the patient's ability to follow commands and sustain muscular contraction (Carvalho et al., 2020; Domenech et al., 2019; Murphy et al., 2011; Murphy et al., 2008; Samet et al., 2005; Wardhana et al., 2019). This approach has led to many patients being transported to the PACU with some level of chemical neuromuscular blockade, known as postoperative residual paralysis, still present.

Conversely, each study demonstrated reduced postoperative residual paralysis when quantitative neuromuscular monitoring was used compared to qualitative. Due to the overwhelming evidence in the literature, implementing intraoperative quantitative monitoring to guide tracheal extubation could likely improve the incidence of postoperative residual paralysis. Therefore, the DNP final scholarly project focuses on using quantitative neuromuscular monitoring and the incidence of postoperative residual paralysis, a consistently measured outcome in every article.

Postoperative Residual Paralysis

The main conclusion consistent across the articles analyzed was a reduction in postoperative residual paralysis, defined as a TOFR less than 0.9, when quantitative monitoring was used compared to qualitative techniques (Carvalho et al., 2020; Domenech et al., 2019; Murphy et al., 2011; Murphy et al., 2008; Samet et al., 2005; Wardhana et al., 2019). Notably, the meta-analysis performed by Carvalho et al. (2020) looked at 12,664 patients across 53 studies and found a significant reduction in postoperative residual paralysis when quantitative as opposed to qualitative neuromuscular monitoring was used. Furthermore, in the 155-patient randomized control trial by Murphy et al. (2011), only 14.5% of patients monitored

quantitatively presented to the PACU with postoperative residual paralysis compared to 50% of qualitatively monitored patients. This data is additionally supported by the 185-patient randomized control trial by Murphy et al. (2008), displaying 4.5% of quantitatively monitored patients presenting with postoperative residual paralysis compared to 30% of qualitatively monitored patients.

While the overwhelming majority of evidence suggests a significant decrease in postoperative residual paralysis, one randomized control trial by Wardhana et al. (2019) only demonstrated a reduction in postoperative residual paralysis without statistical significance (P=1.07). However, the abovementioned studies deliver significant evidence favoring quantitative neuromuscular monitoring during the perioperative period. As shown in the research, quantitative monitoring can reduce the incidence of postoperative residual paralysis and its adverse effects. Developing guidelines for quantitative neuromuscular monitoring is paramount in advancing patient safety in the perioperative setting.

Barriers to Quantitative Monitoring

Although quantitative monitoring has displayed the ability to decrease postoperative residual paralysis in patients recovering from chemical neuromuscular blockade, there are still barriers and limitations to its use, specifically with acceleromyography use. Acceleromyography was the most utilized quantitative monitoring device in the literature review (Carvalho et al., 2020; Domenech et al., 2019; Murphy et al., 2011; Murphy et al., 2008; Samet et al., 2005; Wardhana et al., 2019). However, several of the authors stated that research has demonstrated that acceleromyography can overestimate the TOFR in patients, which can lead to a false sense of neuromuscular recovery and early tracheal extubation (Carvalho et al., 2020; Murphy et al., 2011; Murphy et al., 2008). In the quasi-experimental study by Samet et al. (2005), a secondary

aim of the study was to measure the time it took to obtain a TOFR greater than 0.9 with mechanomyography after an acceleromyography reading of 0.9. Mechanomyography is commonly revered as the gold standard of quantitative monitoring. When acceleromyography readings were 0.9, it took an average of four minutes for mechanomyography readings to reach the same level of recovery (Samet et al., 2005). As research demonstrates, quantitative neuromuscular monitoring with acceleromyography improves the incidence of postoperative residual paralysis. However, guidelines for what constitutes recovery may need to be adjusted to account for its overestimation.

Project Design

Evidence-Based Practice Model

Changing the clinical practice of a healthcare system poses significant challenges. As a result, framework models have been developed to systematically guide healthcare providers through the evidence-based practice (EBP) research and implementation process to promote new practice guidelines that aim to improve patient care (Melnyk & Fineout-Overholt, 2019). Specifically, this scholarly project will use the John Hopkins Evidence-Based Practice for Nurses and Healthcare Professionals (JHEBP) Model. The JHEBP Model provides a framework that leads nurses and healthcare professionals through the EBP process and guides their clinical decision-making through research-proven methods, displaying positive patient outcomes (Dang et al., 2022). Appendix B shows the author's granted permission to use the JHEBP Model via the Copyright Permission Form on July 3, 2023. The model's foundation is clinical inquiry and reflection to promote the development of a practice question, analysis of relevant evidence, and translation into clinical practice, as depicted in Appendix C (Dang et al., 2022). The author and project team will regularly inquire and reflect on research and current clinical practices during

the project. As a result, the JHEBP Model is an applicable framework for instituting guidelines for quantitative neuromuscular monitoring in the operating room.

Methods

The JHEBP Model is a systematic approach to EBP implementation that institutes the PET process: practice question, evidence, and translation to practice (Dang et al., 2022). Significant to the JHEBP Model is the opportunity for clinical inquiry and revision at any time throughout the model, sparking a new EBP cycle and ensuring the most up-to-date practices (Melnyk & Fineout-Overholt, 2019). Appendix D outlines the specific steps in each part of the PET process within the JHEBP Model.

JHEBP: Practice Question

The first phase of the JHEBP Model involves discovering the clinical practice question. According to Dang et al. (2022), the practice phase begins with recruiting an interprofessional team to define the problem in the field. Next, the team develops and refines the PICO question, identifies stakeholders, and determines responsibility for the project throughout regular meetings (Dang et al., 2022). To begin this final scholarly DNP project, the author sought guidance from experts in the field and recruited an interprofessional team. The team comprises a DNP student, a doctorally prepared professor at Otterbein University, a nurse anesthesia program assistant director, and other nursing faculty at Otterbein University. Within the team, leadership responsibility was awarded to the Otterbein University professor to guide the project toward completion.

With the help of the interprofessional team, the chosen problem related to nurse anesthesia was postoperative residual paralysis following chemical paralysis in patients monitored with traditional, qualitative monitoring techniques in the operating room.

Additionally, the team identified critical stakeholders related to the clinical problem, including patients, hospital staff in the perioperative setting, hospital administrators, and perioperative equipment supply coordinators. Patients are a significant stakeholder in this final scholarly project because non-maleficence is a core pillar of nursing care. Preventing patient harm is a top priority in the nurse anesthesia profession, and implementing techniques to improve patient safety is crucial. Hospital staff, specifically certified registered nurse anesthetists (CRNAs) and anesthesiologists, are essential stakeholders in the project as they will use the guidelines daily.

Moreover, administrators will be instrumental in adopting said guidelines because they are vital in approving and implementing system-wide guidelines and culture. Lastly, supply coordinators in the perioperative setting will be foundational in acquiring and maintaining the devices used in quantitative monitoring. Routine meetings by the stakeholders will be essential for the success of the guidelines to monitor for effectiveness in reducing postoperative residual paralysis, compliance with device usage, and ensuring a sufficient quantity and operating quality of the devices.

JHEBP: Evidence

The following phase of the JHEBP Model examines the pertinent and available evidence related to the practice question. Dang et al. (2022) explain that the evidence phase starts by conducting a literature search to compile relevant evidence to the clinical problem. Additionally, the team will appraise the level and quality of evidence (Dang et al., 2022). Next, a summary of the individual evidence and synthesis of the overall quality and strength of the evidence will guide the recommendation development in the guidelines (Dang et al., 2022). The team conducted a literature review to discover and appraise high-quality evidence addressing the practice question to influence practice change. The literature review summarized and synthesized

evidence related to quantitative neuromuscular monitoring in the intraoperative period and its effect on residual paralysis post-tracheal extubation. The interprofessional team utilized the evidence to lead their guideline recommendation development. A complete summary of the literature review and outcomes of utilizing quantitative neuromuscular monitoring is described in the Review of Literature section of the paper. Additionally, Appendix E, the evidence review worksheet, comprises an extensive breakdown of the relevant evidence related to the practice question.

JHEBP: Translation

Evidence translation is the final phase of the PET process of the JHEBP Model. To transition the model to practice, the translation phase consists of identifying specific recommendations for the practice setting and creating an action plan tailored to the hospital system. (Dang et al., 2022). The phase further comprises secured support and resources to implement the action plan (Dang et al., 2022). To complete the transition to practice, the team evaluates the effect to determine improved patient outcomes, reports the results to the stakeholders, identifies the following steps, and spreads the findings to the hospital system-wide (Dang et al., 2022). Effectiveness will reduce the incidence of postoperative residual paralysis. At the same time, a continuation of stakeholder meetings will allow open communication between the interprofessional team and stakeholders for reporting results, identifying the following steps, and disseminating the findings. The project team's ability to develop a comprehensive translation to practice plan will be instrumental to the final scholarly project’s success and improvement in patient outcomes.

Implementation Plan

The project team developed a three-phase approach to implementing the final scholarly project. Each phase involves compliance by anesthesia providers and other key stakeholders previously mentioned. The plan comprises pre-implementation data collection, preliminary implementation, and post-implementation data collection.

Phase 1: Pre-implementation

Before initiating the implementation plan, the project team investigates the clinical area and recognizes a need for change. The identified need for change sparks EBP questioning and research to develop guidelines for intraoperative quantitative neuromuscular monitoring use. The project team then presents the information to hospital administrators for the approval necessary to enact practice change. Additionally, the team must contact the Institutional Review Board (IRB) for permission to proceed with the project. Once approval is granted, the project team will coordinate with the perioperative equipment supply department to ensure adequate quantitative monitoring devices are available in every operating room. Smooth and continuous collaboration between the project team, hospital administrators, and equipment department will be required, so monthly meetings will be planned to discuss the progression of the guideline implementation.

In addition to coordination between the stakeholders, the first phase involves postoperative residual paralysis data collection in the implementation facility. The current standard neuromuscular monitoring practice utilizes qualitative monitoring. Therefore, according to the data, many patients are left with residual paralysis even after neuromuscular blockade reversal. The pre-implementation phase data collection portion will analyze all scheduled surgical patients and mark the previously defined high-risk patients for further analysis. Within

the subset of high-risk patients, patients scheduled for surgery with tracheal intubation and neuromuscular blocking agent use will be included in the data collection.

The data collection will include a quantitative TOFR measurement by a dedicated PACU anesthesia provider within five minutes of arrival to the PACU using the Stimpod NMS 450x quantitative neuromuscular monitoring device. A device representative will educate the anesthesia provider on proper device utilization before collecting the data. The anesthesia provider will assess for residual paralysis, defined as a TOFR less than 0.9, using a one-time stimulation at strength level 5. The data collection will include 100 patients and measure the facility's postoperative residual paralysis rates while utilizing standard qualitative monitoring to guide tracheal extubation. The patients enrolled in the study will be reversed using the APSF guidelines for reversal agents, found in Appendix A, and extubated when deemed clinically appropriate by the responsible provider. The data will then be used to evaluate the effectiveness of the guidelines following implementation.

Phase 2: Preliminary Implementation

Phase two of the implementation plan is a preliminary implementation of the intraoperative quantitative neuromuscular monitoring guidelines. To begin this phase, the anesthesia providers will be provided with an in-service for further education on device utilization to build on the foundation they received in the first phase. A device representative will come in for a two-hour block during the morning of each "late-start" day for a month to educate the anesthesia department on correct usage. The anesthesia department holds meetings during this time, allowing ample time for each staff member to be educated on the device.

Following adequate education on the quantitative monitor, anesthesia providers will begin routine intraoperative use of the monitors to guide tracheal extubation to prevent residual

paralysis postoperatively. The guidelines for correct use are derived from Thilen et al. (2023) and their 2023 ASA Practice Guidelines for neuromuscular monitoring. After administering the appropriate reversal agent, the anesthesia providers will wait for a TOFR of 0.9 on the quantitative monitor before extubating the patient. During the preliminary implementation phase, the stakeholder meetings will persist uninterrupted to discuss progress and observations. The phase will continue until quantitative neuromuscular monitoring has been performed on 100 high-risk surgical patients.

Phase 3: Post-implementation

Upon completion of the preliminary implementation in phase two, the final phase will involve more data collection, results analysis, and dissemination of the findings. The data collected in the first phase will also be collected in phase three on the 100 patients monitored with quantitative neuromuscular monitoring. After the data is collected, it will be analyzed and cross-referenced to the original facility data, intending to show reduced postoperative residual paralysis. Additionally, compliance with the guidelines will be paramount to its successful implementation, so data will be collected to measure compliance among anesthesia providers. The Stimpod NMS 450x uses direct connectivity to the EMR via a cable that will transmit data for each patient into the medical record. Compliance will be measured by auditing each patient's EMR to see if a TOFR of 0.9 or greater was achieved before extubation.

During the post-implementation phase, the project team will identify if the desired outcomes were met. If they are not, the team will evaluate the necessary steps to adjust the plan to meet the desired outcomes, whether that be improved compliance, stricter TOFR, etc. Lastly, once the appropriate outcomes are reached, the project team will disseminate the findings throughout the facility through newsletters, staff meetings, and email.

Timeline for Implementation

The timeline for implementation of this final scholarly project will reference Appendix F and will take approximately ten months. The IRB approval process may prove lengthy as they often meet monthly; thus, the project team will allow one month for IRB approval. Obtaining the quantitative monitoring devices will take another month, from coordination with the device representatives to order placement, device shipment, and device delivery. The setting for this project, a level 1 trauma center in a large, metropolitan, midwestern area, sees a large population of high-risk patients in the operative setting. Therefore, the project team will allot three months for the initial data collection on the facility's residual paralysis rates with their standard qualitative monitoring techniques on 100 patients. Following the data retrieval, the analysis of the collected data will take approximately two weeks.

During the analysis period, the team will begin to coordinate in-service dates and times and gather online training material for anesthesia providers to familiarize themselves with the new technology. Because the facility has never utilized quantitative monitoring, mandatory in-service training will be required before preliminary implementation. The team will provide opportunities for in-person training sessions with a device representative before, during, and after scheduled shifts. If scheduling conflicts prevent the personnel from attending the meetings, online education will be provided by the device manufacturer so that the anesthesia staff can complete it away from the facility. The team projects an additional two weeks for the initial anesthesia provider training on the quantitative neuromuscular monitoring device.

Following the training, the preliminary implementation of the quantitative neuromuscular guidelines will take another three months to trial the guidelines on 100 high-risk patients. The data collection analysis of said patients and cross-reference to the initial data will take another

two weeks. While the data is being analyzed, the project team will offer additional training to ensure provider competency and comfort with the new quantitative monitoring devices. The time needed to adjust the quantitative neuromuscular monitoring guidelines to optimize outcomes may fluctuate depending on the level of need. However, the project team aims to refine the guidelines and disseminate the findings throughout the facility within one month in preparation for the final guideline roll-out.

Product Selection & Financial Considerations

Of the various quantitative neuromuscular monitors on the market, the project team chose the Stimpod NMS 450x. The Stimpod NMS 450x device is particularly advantageous because it is the only available device capable of monitoring with acceleromyography and electromyography (Xavant Technology, n.d.). Utilizing both modalities for monitoring is beneficial because research has shown that each quantitative technique is superior to qualitative monitoring. Additionally, the acceleromyography mode offers a reusable sensor that boasts affordability (Xavant Technology, n.d.). On the other hand, the electromyography capabilities are optimal for procedures where acceleromyography is impossible, such as when a patient's arms are tucked. Anesthetists will be able to utilize quantitative monitoring no matter the circumstances of the surgery, with both electromyography and acceleromyography available on the neuromuscular monitoring device.

The main cost of the project comes from the equipment expense. The cost of one Stimpod NMS 450x device is $1,995 (Bell Medical, n.d.-b). To effectively monitor chemically paralyzed surgical patients, there needs to be one device in each operating room at the facility. The level 1 trauma center has 29 operating rooms, making the total cost of quantitative monitors $57,855. Additional financial considerations come from the electrodes needed for monitoring with

electromyography. The price is $220 per box of ten electrodes (Bell Medical, n.d.-a). Although the majority of monitoring will be with the reusable acceleromyography sensor, the facility should have sufficient electrodes in stock. Thus, the project team estimates about ten boxes of electrodes, equating to $2,200. The last equipment cost is the electronic medical record (EMR) communication cable, costing $400; the total cable cost is $11,600.

The secondary cost of the project comes from training the anesthesia providers to use the monitors. The project team estimates that one-hour training sessions will be sufficient to complete the necessary education. The hourly rate for CRNAs at the facility is $106, and 30 CRNAs training for one hour totals $3,540. The anesthesiologists at the facility are paid a salary, but their average salary equates to an hourly rate of approximately $230. Training the 20 anesthesiologists on staff for one hour each equals $4,600. The total budget for the project is $79,79, and Appendix G depicts a table breaking down the individual cost items.

Outcomes and Analysis

The outcomes of the DNP project will be analyzed during the post-implementation phase. The project team and the quality improvement (QI) department at the target facility will analyze the data collected on postoperative residual paralysis before guideline implementation and cross-reference it to the postoperative residual paralysis data in the preliminary implementation phase. The team will calculate a p-value by comparing the two data sets. The goal p-value will be less than 0.05 to prove the statistical significance of the quantitative neuromuscular monitoring guidelines and reject the null hypothesis. If the project team and QI department calculate a p-value less than 0.05, the data supports permanent implementation of the proposed guidelines to improve the incidence of postoperative residual paralysis.

To ensure reliability and validity, the project team and QI department will audit compliance with the guidelines, as discussed previously. A compliance rate of at least 90% will be used to determine whether accurate data has been collected. To comply, the anesthesia providers must utilize the quantitative neuromuscular monitor, have a documented TOFR of at least 0.9 before tracheal extubation, and a documented TOFR within five minutes of PACU arrival. If the compliance metric is unmet, additional patients will be enrolled in the study to ensure reliable and valid data.

Recommendations and Conclusions

Limitations and Future Direction

There are several limitations to the final scholarly project. Most notably, the proposed implementation plan's financial burden on the anesthesia department is significant. Additionally, the long-standing culture of the current anesthesia providers' practice may limit the implementation of the guidelines. Furthermore, the overall scope of the study is limited due to its smaller scale and single-center focus compared to similar multi-center designs utilized in comparable research. Lastly, the study lacks implementation results, while the outcomes analysis is purely hypothetical.

At the conclusion of the project, several additional components became evident for future inclusion to ensure proper adoption of the proposed guidelines. Notably, adding a cost analysis between healthcare costs associated with postoperative pulmonary complications arising from residual paralysis and the purchase, staff training, and implementation of the Stimpod NMS 450x would be prudent in convincing hospital administrators to adopt the proposed guidelines. Moreover, expanding the study to include a larger, more diverse patient population may improve its reliability, making it proportionate to the previously mentioned multi-center design studies.

With the mentioned study supplements, department leaders and hospital administrators may be more inclined to adopt the final scholarly project guidelines.

Conclusion

Postoperative residual paralysis continues to be a prevalent and devastating problem impeding anesthetic and surgical recovery for many patients. The corresponding research on the effects of quantitative neuromuscular monitoring and the incidence of postoperative residual paralysis supports the implementation of guidelines to combat the issue. By implementing guidelines supported by the vast collection of research and multiple professional organizations, including the ASA, the project team anticipates a statistically significant improvement in postoperative residual paralysis rates. The project team looks forward to continuous inquiry regarding quantitative neuromuscular monitoring to improve patient outcomes, implement additional evidence-based practice advancements, and lead to positive change beyond the scope of the target facility.

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Appendix A

Anesthesia Patient Safety Foundation Reversal Algorithm

SUMMARY OF RECOMMENDATIONS[1]

1. When neuromuscular blocking drugs are administered, we recommend against clinical assessment alone to avoid residual neuromuscular blockade, due to the insensitivity of the assessment.[1]

2. We recommend quantitative monitoring over qualitative assessment to avoid residual neuromuscular blockade.

3. When using quantitative monitoring, we recommend confirming a train of four ratio greater than or equal to 0.9 before extubation.

4. We recommend using the *adductor pollicis* muscle for neuromuscular monitoring.

5. We recommend against using eye muscles for neuromuscular monitoring.

6. We recommend sugammadex over neostigmine at deep, moderate, and shallow depths of neuromuscular blockade induced by rocuronium or vecuronium, to avoid residual neuromuscular blockade.

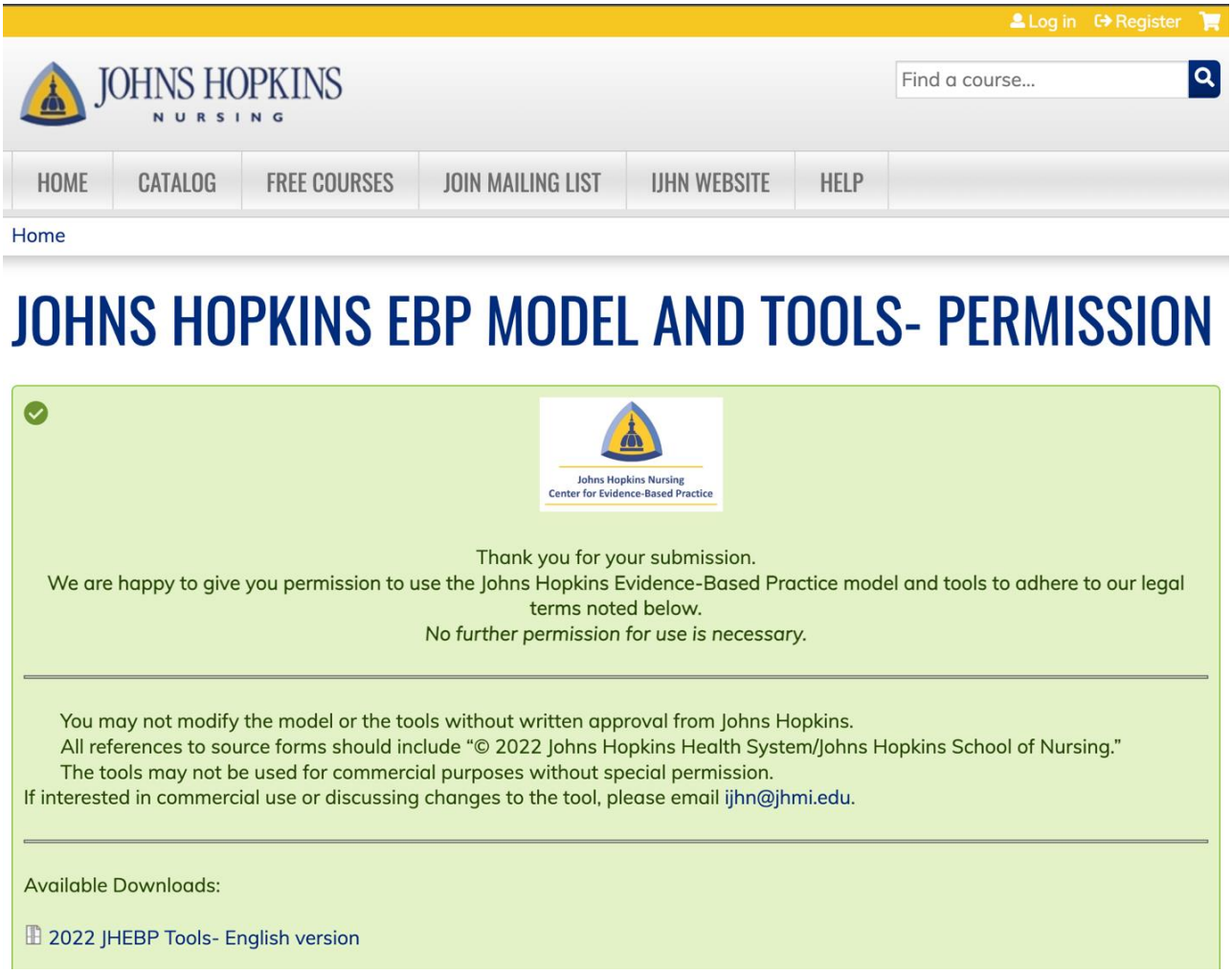
7. We suggest neostigmine as a reasonable alternative to sugammadex at minimal depth of neuromuscular blockade.

8. To avoid residual neuromuscular blockade when atracurium or cisatracurium are administered and qualitative assessment is used, we suggest antagonism with neostigmine at minimal neuromuscular blockade depth. In the absence of quantitative monitoring, at least 10 minutes should elapse from antagonism to extubation. When quantitative monitoring is utilized, extubation can be done as soon as a train of four ratio greater than or equal to 0.9 is confirmed before extubation.

Depth of Blockade	Peripheral Nerve Stimulator and Qualitative Assessment	Quantitative Monitor
Complete	Posttetanic count = 0	Posttetanic count = 0
Deep	Posttetanic count ≥ 1; train-of-four count = 0	Posttetanic count ≥ 1; train-of-four count = 0
Moderate	Train-of-four count = 1–3	Train-of-four ratio = 1–3
Shallow*	Train-of-four count = 4; train-of-four fade present	Train-of-four ratio < 0.4
Minimal*	Train-of-four count = 4; train-of-four fade absent	Train-of-four ratio = 0.4–0.9
Acceptable recovery	Cannot be determined	Train-of-four ratio ≥ 0.9

Appendix B

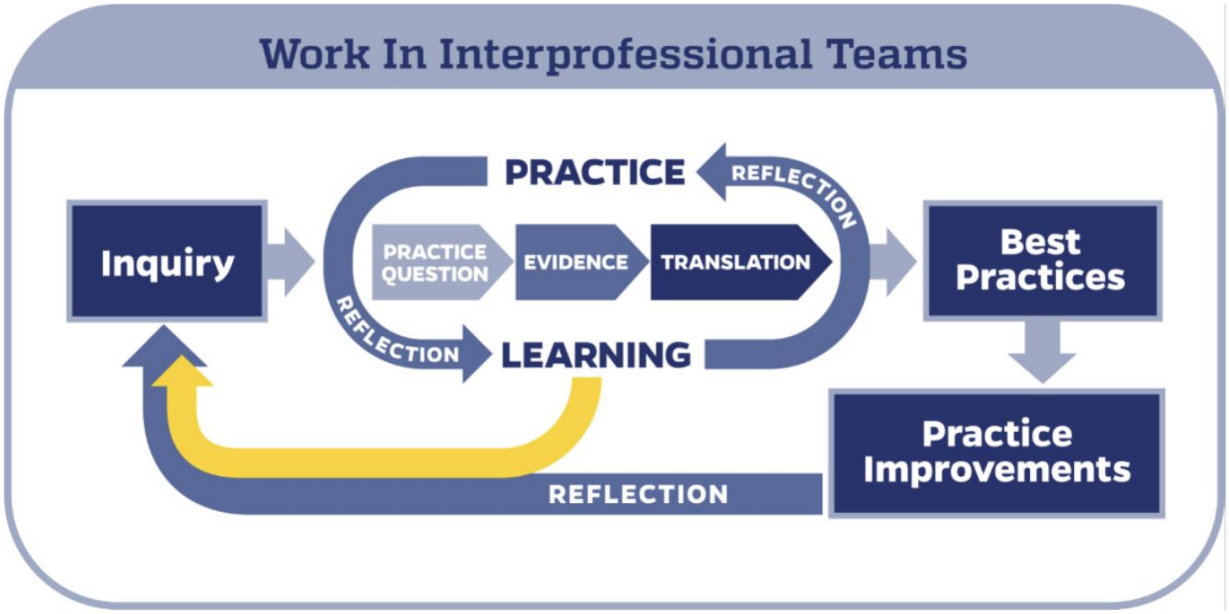
John Hopkins Permission Form



Note. © 2022 Johns Hopkins Health System/Johns Hopkins School of Nursing.

Appendix C

John Hopkins Evidence-Based Practice Model



Note. © 2022 Johns Hopkins Health System/Johns Hopkins School of Nursing.

Appendix D

JHEBP PET Process Guide

EBP Work Plan										
Initial EBP question:										
EBP team leader(s):										
EBP team members:										
Goal completion date:										
	Steps	Month								
		1	2	3	4	5	6	7	8	9
Practice Question & Project Planning	1. Recruit interprofessional team									
	2. Determine responsibility for project leadership									
	3. Schedule team meetings									
	4. Clarify & describe the problem (App. B)									
	5. Develop & refine the EBP question (App. B)									
	6. Determine the need for an EBP project									
	7. Identify stakeholders (App. C)									
Evidence	8. Conduct internal & external search for evidence									
	9. Appraise the level & quality of each piece of evidence (Apps. E/F)									
	10. Summarize the individual evidence (App. G)									
	11. Synthesize findings (App. H)									
	12. Develop best evidence recommendations (App. H)									
Translation	13. Identify practice setting–specific recommendations (App. I)									
	14. Create action plan (App. I)									
	15. Secure support & resources to implement action plan									
	16. Implement action plan									
	17. If change is implemented, evaluate outcomes to determine if improvements have been made									
	18. Report results to stakeholders (App. C)									
	19. Identify next steps									
	20. Disseminate findings (App. J)									

Appendix E

Evidence Review Worksheet

Appendix A: Evidence Review Worksheet Assignment C								
APA Citation: Carvalho, H., Verdonck, M., Cools, W., Geerts, L., Forget, P., & Poelaert, J. (2020). Forty years of neuromuscular monitoring and postoperative residual curarisation: A meta-analysis and evaluation of confidence in network meta-analysis. *British Journal of Anaesthesia*, *125*(4), 466–482. https://doi.org/10.1016/j.bja.2020.05.063								
Conceptual Framework or Model	***Design or Method***	***Sample & Setting***	***Major Variables Studied & their Definitions, if any***	***Outcome Measurement(s)***	***Data Analysis***	***Findings***	***Level of Evidence***	***Quality of Evidence: Critical Worth to Practice***
Theoretical basis for the study: N/A	Meta-analysis: a comprehensive search was performed using the following databases: PubMed, Cochrane Central Register of Controlled Trials, ISI Web of Knowledge, and Scopus. Three reviewers screened the potential eligible studies and extracted data on intervention and control conditions, neuromuscular blocking agent (NMBA) used and dose, NMBA duration category, type of anesthesia, duration of anesthesia, use of neostigmine or sugammadex, and outcomes.	**Number of Characteristics :** a total of 12,664 patients from 53 studies were included in the meta-analysis. **Exclusion Criteria:** short-acting NMBA use, train-of-four ratio (TOFR) cut off of <1.0 **Setting:** operating room anesthesia	**Independent variables:** 1. Type of neuromuscular monitoring used intraoperatively: quantitative monitoring (TOFR quantification), qualitative monitoring (peripheral nerve stimulation (PNS), or no monitoring 2. Duration category of NMBA: intermediate-acting (atracurium, cisatracurium, mivacurium, vecuronium, and rocuronium) or long-acting (gallamine, pancuronium, and d-tubocurarine)	- The primary outcome of the meta-analysis was the incidence of PORC at or post-tracheal extubation as defined as TOFR lower than 0.7 or 0.9. - Each statistical model was evaluated using both TOFR cut-offs	- The statistical analysis was subdivided into three categories: 1. Main model: variables included were neuromuscular monitoring (NMM) type, NMBA category, and anesthesia maintenance technique 2. Antagonist model: variables included were NMM type, anesthesia maintenance technique, and antagonist drug used	**Main Model:** - 0.9 TOFR cut-off: quantitative NMM results in less PORC than no monitoring (coefficient of 0.208; 95% CI, 0.048 to 0.368; P=0.005) and qualitative NMM (coefficient of 0.269; 95% CI, 0.423 to 0.114; P<0.001) **Antagonist Model:** - 0.7 TOFR cut-off: there is only a difference between quantitative NMM and no monitoring (coefficient-=0.264; 95% CI, 0.051 to 0.477; P=0.009) - 0.9 TOFR cut-off: quantitative NMM resulted in lower PORC than qualitative NMM (coefficient=0.259; 95% CI, 0.413 to 0.106; P<0.001) and no	I	**Strengths:** the study used a meta-analysis model allowing for an extensive evaluation of many studies. Additionally, a search strategy utilizing multiple databases was performed. A vast number of studies, 53, were used and included many participants, 12,664 resulting in a generalizable conclusion. **Limitations:** The TOFR time point measurement varied across the studies, with some taking place right at tracheal extubation and some taking place post-recovery room arrival. Additionally, with measurement in

			3. Antagonist drugs used: neostigmine or sugammadex 4. Anesthesia maintenance technique: volatile anesthetics, total intravenous anesthesia (TIVA), or both 5. Year of publication **Dependent variables:** 1. Incidence of postoperative residual curarisation (PORC): defined as a TOFR of less than 0.7, 0.9, and 1.0		3. Trend model: variables included were NMM and publication year to make an evolution analyses of monitoring use. - 95% confidence interval (95% CI)	monitoring (coefficient=0.214; 95% CI, 0.055 to 0.372; P=0.004). Sugammadex resulted in lower PORC than neostigmine (coefficient=0.196; 95% CI, 0.060 to 0.332; P=0.002) **Trend model:** **-** 0.7 TOFR cut-off: there is a small reduction of PORC with quantitative NMM than no monitoring (coefficient=0.221; 95% CI, 0.012 to 0.430; P=0.035) - 0.9 TOFR cut-off: quantitative NMM results in less PORC than qualitative NMM (coefficient=0.236; 95% CI, 0.343 to 0.129; P<0.001) and no monitoring (coefficient=0.246; 95% CI, 0.136 to 0.355; P<0.001) -The meta-analysis found that intraoperative quantitative NMM significantly reduces PORC compared to qualitative and no NMM. When using a TOFR cut-off of 0.7, no significant difference		the recovery room, patients may have been moving resulting in skewed and improved results from TOFR monitoring. Moreover, acceleromyography was a bulk of the quantitative NMM method and is known to over-estimate the TOFR; which is why there has been a call for stricter guidelines for the definition of PORC (i.e. TOFR >0.95). **Feasibility of use in the project practice area:** The resource has excellent feasibility as it pertains directly to my PICOT question outcomes.

						between the varying NMM modalities can be found. However, using the more consensual TOFR cut-off of 0.9, quantitative significantly decreased the incidence of PORC compared to qualitative and no NMM.		

Will complete this in Assignment E

Annotated Bibliography statement (may be several sentences summarizing the article based upon the information above using professional APA writing style):
The authors conducted a meta-analysis of 53 studies, consisting of 12,664 patients. Within the meta-analysis, the authors studied whether using quantitative monitoring, qualitative monitoring, or no monitoring affected the incidence of post-operative residual paralysis. Post-operative residual paralysis was defined as either a train-of-four ratio (TOFR) of less than 0.7 or less than 0.9. Additionally, the meta-analysis included three different models to test multiple variables on the incidence of post-operative residual paralysis. The main model included neuromuscular monitoring type, neuromuscular blocking agent category, and anesthesia maintenance technique. The antagonist model measured the neuromuscular monitoring type, anesthesia maintenance technique, and the neuromuscular blocking antagonist drug used. Lastly, the trend model included neuromuscular monitoring type and publication year. The meta-analysis displayed advantageous results when using quantitative neuromuscular monitoring. Specifically, quantitative monitoring resulted in less post-operative residual paralysis than qualitative and no monitoring in every model when post-operative residual paralysis was defined as a TOFR of less than 0.9. In the antagonist and trend model, quantitative monitoring did not always result in less post-operative residual paralysis than qualitative monitoring when the TOFR cut-off was 0.7. However, quantitative monitoring always resulted in less post-operative residual paralysis than no monitoring.

Thematic Analysis/Key Themes or FSP related significance:
1. Quantitative neuromuscular monitoring resulted in less post-operative residual paralysis than qualitative when a TOFR of 0.9 was used.
2. Quantitative neuromuscular monitoring resulted in less post-operative residual paralysis than no monitoring when a TOFR of 0.7 or 0.9 was used.
3. Level 1 evidence

Appendix A: Evidence Review Worksheet Assignment C								
APA Citation: Domenech, G., Kampel, M. A., García Guzzo, M. E., Novas, D., Terrasa, S. A., & Fornari, G. (2019). Usefulness of intra-operative neuromuscular blockade monitoring and reversal agents for postoperative residual neuromuscular blockade: A retrospective observational study. *BMC Anesthesiology*, *19*(1). https://doi.org/10.1186/s12871-019-0817-4								
Conceptual Framework or Model	***Design or Method***	***Sample & Setting***	***Major Variables Studied & their Definitions, if any***	***Outcome Measurement(s)***	***Data Analysis***	***Findings***	***Level of Evidence***	***Quality of Evidence: Critical Worth to Practice***
Theoretical basis for the study: N/A	Retrospective cohort study: a medical chart review of 240 patients undergoing elective surgeries requiring neuromuscular blocking drugs (NMBDs) was conducted.	**Number of Characteristics:** 240 patients undergoing elective surgery with NMBD use. **Exclusion Criteria:** scheduled recovery time in the intensive care unit **Attrition:** **Setting:** Argentinian university hospital	**Independent variables:** 1. Use of quantitative neuromuscular monitoring 2. Type of reversal agent: neostigmine or sugammadex 3. Duration of surgery 4. Time between the last dose of NMBD and the presence of a train-of-four ratio (TOFR) in the post-anesthesia care unit (PACU) 5. Type of NMBD used **Dependent variables:** 1. Incidence of residual neuromuscular blockade (RNMB): TOFR >0.9	- The primary outcome of this study is to estimate the incidence of RNMB as defined as TOFR <0.9 - The secondary aims of the study were the associations between RNMB and potentially related variables	- The study sample size allowed a RNMB incidence estimation with a 95% CI (CI) margin of error that did not exceed 7% - Qualitative variables were analyzed using the chi-square test or the Fischer's exact test - The Student's t-test was used to analyze normally distributed quantitative data. The Wilcoxon rank sum-test was used to analyze non-	- 58/240 (24%) of the patients presented with RNMB. - 1/63 (1.6%) of the patients monitored with quantitative neuromuscular blockade (NMB) monitoring had RNMB. 57/177 (32%) of the patients who were not monitored had RNMB (P<0.01). - 5/177 patients that were not monitored received neostigmine as the reversal, with 2/5 (40%) presenting with RNMB (P=0.11). - 19/177 patients that were not monitored received sugammadex as the reversal. 3/19 (16%) presented without blockade reversal while none of the monitored patients receiving sugammadex had RNMB (P=0.028). - Multivariable analysis revealed that using quantitative NMB monitoring results in a lower incidence of RNMB, with a calculated odds ratio (OR) of 0.04 (95% CI: 0.005 to 0.401. Additionally, using sugammadex reduces the incidence of RNMB with an	IV	**Strengths:** The study presents a clear benefit to using quantitative NMB monitoring over no monitoring in the sample. **Limitations:** The study was observational in a single center making it hard to generalize the findings. Physicians in charge of TOFR monitoring were not blinded to the type of NMBD used. Also, two monitors were used to measure the TOFR using acceleromyography methods. Additionally, the sample size who received antagonists was limited making it hard to draw conclusions on this. Lastly, the temperature was not monitored in the PACU which would impact TOFR. **Feasibility of use in the project practice area:** The study

					normally distributed quantitative data.	OR of 0.18 (95% CI: 0.046 to 0.727). - A longer period of time between last NMBD dose and TOFR in the PACU resulted in a lower incidence of RNMB (OR, 0.98; 95% CI: 0.977 to 0.995) - The incidence of RNMB in quantitatively monitored patients was significantly lower than in the non-monitored patients. - Anesthesia providers who utilized monitoring are more likely to use reversal agents. - Sugammadex administration in the absence of monitoring is not an effective strategy to avoid RNMB.		appropriately addresses the PICOT question's outcomes. However, the observational nature and sample characteristics makes it hard to generalize the finds for guidelines for quantitative monitoring use. Additionally, no qualitative TOFR monitoring was used.

Will complete this in Assignment E

Annotated Bibliography statement (may be several sentences summarizing the article based upon the information above using professional APA writing style):
The authors conducted a retrospective cohort study of 240 patients' charts that underwent elective surgery with neuromuscular blockers used. The study measured the incidence of post-operative residual paralysis, defined as a train-of-four ratio (TOFR) less than 0.9, when using quantitative monitoring versus no monitoring. The study found that quantitative monitoring resulted in less post-operative residual paralysis than when anesthetists did not monitor for neuromuscular blockade. Additionally, the authors noted that sugammadex administration and a longer period of time between the last dose of neuromuscular blocker and TOFR resulted in less residual paralysis.

Thematic Analysis/Key Themes or FSP related significance:
1. Quantitative monitoring resulted in less post-operative residual paralysis than no monitoring when a TOFR of 0.9 was used.
2. There was no qualitative neuromuscular monitoring included in the observational study.
3. Level IV evidence

Appendix A: Evidence Review Worksheet Assignment C								
APA Citation: Murphy, G., Szokol, J., Avram, M., Greenberg, S., Marymont, J., Vender, J., Gray, J., Landry, E., & Gupta, D. (2011). Intraoperative acceleromyography monitoring reduces symptoms of muscle weakness and improves quality of recovery in the early postoperative period. *Anesthesiology*, *115*(5), 946–954. https://doi.org/10.1097/aln.0b013e3182342840								
Conceptual Framework or Model	***Design or Method***	***Sample & Setting***	***Major Variables Studied & their Definitions, if any***	***Outcome Measurement (s)***	***Data Analysis***	***Findings***	***Level of Evidence***	***Quality of Evidence: Critical Worth to Practice***
Theoretical basis for the study: N/A	Randomized control trial: Participants were recruited based on the operating room schedules and contacted the night before surgery for enrollment. With a computer-generated randomization code, patients were randomly (1:1) allocated to the acceleromyography or the control group. Patients in the acceleromyography group were evaluated intraoperatively with quantitative neuromuscular monitoring. While, patients in the control group were monitored with traditional qualitative monitoring, defined as the presence or absence of fade. Group allocation was hidden in an envelope until the patient was induced with anesthesia and neuromuscular monitoring was set up.	**Number of Characteristics:** 155 patients undergoing elective surgery requiring NMBD administration and expected surgery time of 60 minutes. **Exclusion Criteria:** underlying neuromuscular disease, use of drugs known to interfere with neuromuscular transmission, renal insufficiency or failure, hepatic disease, age <18 years, surgeries that prevented access to the ulnar area of the wrist **Attrition:** Five patients were excluded due to	**Independent variables:** - Overall weakness scores: patients' quantification of muscle weakness (0-10). - Total number of symptoms of muscle weakness: asked if the eleven objective signs of muscle weakness were "hard" or "easy"; recorded as "positive response" and "negative response," respectively - Total number of signs of muscle weakness at the four measurement times in the PACU (0, 20, 40, and 60 minutes): 5-s head lift; 5-s hand grip; 5-s eye-opening; 5-s tongue protrusion; tongue depressor test (prevent removal of a wooden tongue depressor from be- tween the incisor teeth); ability to smile; ability to swallow; ability to speak; ability	- The study's primary outcome was to determine the incidence of RNMB when using quantitative neuromuscular monitoring compared to qualitative neuromuscular monitoring intraoperatively to guide tracheal extubation. - The secondary outcomes were to determine if acceleromyography would reduce the symptoms of residual paralysis.	- The primary outcomes consisted of count data, and generalized linear models were used with a Poisson distribution and log link. - The criterion for rejecting the null hypothesis in the analysis of each of the three primary outcome variables was P <0.05/3=0.0167. - The possible relationships between signs and symptoms of muscle weakness in the early	-TOF ratios on admission to the PACU were significantly higher in the acceleromyography group (0.98, range 0.48–1.28) than in the control group (0.88, range 0.33-1.26, P=0.004). - The number of patients with TOF ratios less than 0.9 (14.5% *vs.* 50%, P 0.0001) and TOF ratios less than 0.7 (4.0% *vs.* 18.9%, P 0.004) was smaller in the acceleromyography group than in the control group. - Generalized linear models revealed the acceleromyography group had less overall weakness and fewer symptoms of muscle weakness across all time points (P 0.0001 for both analyses), but the number of signs of muscle weakness was small from the time of arrival in the PACU and did not differ between	II	**Strengths:** A well-executed randomized control trial is a strong level of evidence. This study standardized the anesthetic processes before knowing the patient's group. Additionally, the monitoring in the PACU was standardized by a blinded observer who performed the same protocol for every patient. **Limitations:** The ability of the acceleromyography device to detect RNMB is improved when calibrated for every patient before NMBD administration. Acceleromyography has been known to overestimate TOFR compared to mechanomyography

		protocol violation, leaving 150 left enrolled. **Setting:** The study was performed at a tertiary hospital at the University of Chicago.	to cough; ability to track objects with eyes (follow the finger of examiner); and ability to breathe deeply **Dependent variables:** - Incidence of residual neuromuscular blockade (RNMB): presence of a TOFR <0.9		postoperative period and the TOF ratio were sought using receiver operating characteristic (ROC) curve analysis - The criterion for rejection of the null hypothesis was a two-tailed P 0.01 to help minimize the chance of a type I error.	the groups across time points - The ROC analysis revealed that, although the number of signs of muscle weakness at PACU admission had good specificity (0.940) for a TOF ratio less than 0.9, it had poor sensitivity (0.435) - The use of acceleromyography resulted in a lower incidence of RNMB and decreased the severity of the patient-perceived symptoms of neuromuscular weakness in the post-anesthesia care unit. - Clinical signs or bedside tests were poor indicators of RNMB and were not useful to assess the patient's symptoms of weakness.		, which is revered as the "gold standard." **Risk or harm if implemented:** N/A **Feasibility of use in the project practice area:** The study directly addresses the outcomes in the PICOT question, and therefore, is relevant to the project area. However, the study excluded "high-risk" patients, as defined in my project.

Will complete this in Assignment E

Annotated Bibliography statement (may be several sentences summarizing the article based upon the information above using professional APA writing style):
The authors conducted a randomized control trial with 155 patients undergoing elective surgery with the use of neuromuscular blocking agents. The study aimed to discover the incidence of post-operative residual paralysis when using quantitative monitoring to guide tracheal extubation as opposed to qualitative monitoring. Additionally, the study sought to determine if acceleromyography reduced any feeling of weakness patients may experience post-operatively. The study found that patients monitored via quantitative techniques in the operating room had higher train-of-four ratios (TOFR) in the post-anesthesia care unit (PACU), meaning they were more adequately recovered from the neuromuscular blocking agent. Additionally, the patients with post-operative residual paralysis, defined as a TOFR less than 0.9, were reduced in the quantitative monitoring group compared to the qualitative monitoring group. The study also determined that clinical signs or bedside tests were poor indicators of residual paralysis as opposed to quantitative TOFR monitoring.

Thematic Analysis/Key Themes or FSP related significance:
1. Quantitative monitoring lead to higher TOFR in the PACU than qualitative monitoring.

2. Quantitative monitoring reduced the incidence of post-operative residual paralysis when compared to qualitative monitoring.
3. Patients with neuromuscular, hepatic, and renal disease were excluded from the study.
4. Level II evidence

Appendix A: Evidence Review Worksheet Assignment C								
APA Citation: Murphy, G., Szokol, J., Marymont, J., Greenberg, S., Avram, M., Vender, J., & Nisman, M. (2008). Intraoperative acceleromyographic monitoring reduces the risk of residual neuromuscular blockade and adverse respiratory events in the postanesthesia care unit. *Anesthesiology*, *109*(3), 389–398. https://doi.org/10.1097/aln.0b013e318182af3b								
Conceptual Framework or Model	***Design or Method***	***Sample & Setting***	***Major Variables Studied & their Definitions, if any***	***Outcome Measurement(s)***	***Data Analysis***	***Findings***	***Level of Evidence***	***Quality of Evidence: Critical Worth to Practice***
Theoretical basis for the study: N/A	Randomized control trial: patients were randomly allocated to an acceleromyography or a conventional train-of-four (TOF) group based on computer generation. The acceleromyography group was monitored with the TOF Watch SX, while the conventional group utilized standard qualitative monitoring. The patient group assignments were sealed in an envelope until the patients arrived in the operating room (OR). Upon the discovery of the patient assignment, a research assistant applied the electrodes and explained the monitoring procedure to the anesthesia provider.	**Number of Characteristics:** 185 patients presenting for elective surgery requiring neuromuscular blockade intraoperatively. **Exclusion Criteria:** age younger than 18 or older than 70 years old, expected duration of the surgical procedure less than 60 min, American Society of Anesthesiologists physical (ASA) status IV or V, weight greater than 30% above ideal body weight, presence of an underlying neuromuscular disease, use of drugs known to interfere with neuromuscular	**Independent variables:** - Quantitative neuromuscular monitoring to achieve a train-of-four ratio (TOFR) >0.8 prior to extubation - Qualitative neuromuscular monitoring to achieve the following: sustained head lift or hand grip for more than 5 s, the ability to follow simple commands, a stable ventilatory pattern with acceptable arterial oxygen saturation, and no observation of fade during TOF stimulation (qualitative evaluation of residual	The primary outcomes in the study was incidence of postoperative residual neuromuscular blockade and postoperative hypoxemia	- The 99% confidence intervals (CIs) for the differences in percentages were calculated using the Farrington and Manning score - Ordinal and continuous data found not to have homogeneous variance or to be normally distributed are presented as median and range. Ordinal data and nonnormally distributed continuous data were compared using the Mann–	- Incidence of a TOFR of ≤ 0.9 was lower in the acceleromyography group was lower, 4.5%, than in the conventional group, 30% (P<0.0001). - a significantly higher incidence of severe blockade (TOF 0.70) was observed in the conventional group (13.3%) compared with the acceleromyography group (0%; *P* 0.001) - The Spearman rank correlation coefficient (Rho) for the relationship between TOF count at reversal and the TOF ratio in the PACU for all patients was 0.27 (99% CI, 0.08 – 0.44; *P* 0.0003) - The SpO_2 observed during transportation was significantly lower in the conventional TOF group (94% compared with 96% acceleromyography group; *P* 0.0001). - The percentage of patients with severe hypoxemia during transport was also higher in the conventional TOF group (21.1%) compared with the	II	**Strengths:** Blinding of the research assistants in the postoperative period was performed. A randomized control trial is a high-level of evidence and the study was well executed. **Limitations:** The degree of residual paralysis was measured with acceleromyography, where research has indicated it overestimated the TOFR. The acceleromyography reading in awake postoperative patients has been questioned. Blinding the clinicians caring for the patients intraoperatively was not possible. Only the first 20 minutes of the postoperative period was observed; a longer

		transmission, and preoperative chronic renal or hepatic dysfunction **Attrition:** 6 patients were excluded due to protocol violations and inability to obtain acceleromyography data **Setting:** Hospital in Illinois	neuromuscular blockade) to determine readiness for extubation **Dependent variables:** - Postoperative residual paralysis as defined as TOFR <0.9 - Postoperative hypoxemia as defined as mild hypoxemia (SpO2 90-93%) and severe hypoxemia (SpO2 <90%)		Whitney U test - The criterion for rejection of the null hypothesis was set at *P* <0.01	acceleromyography group (0%, *P* 0.0001). - More patients in the conventional TOF group required an active intervention to maintain a patent airway during the time interval between extubation and PACU admission (11.1% *vs.* 0%; *P* 0.002). - The median baseline SpO_2 values were lower in the conventional TOF group (95%) com- pared with the acceleromyography group (97%; *P* 0.0001). - During the first 30 min of PACU admission, the percentage of patients with episodes of mild (43.3% conventional TOF *vs.* 6.7% acceleromyography) and severe (21.1% conventional TOF *vs.* 0% accelero-myography) hypoxemia was significantly greater in the conventional TOF group (all *P* 0.0001).		time period could exhibit different results **Risk or harm if implemented:** N/A **Feasibility of use in the project practice area:** However, the study excluded "high-risk" patients, as defined in my project.

Will complete this in Assignment E

Annotated Bibliography statement (may be several sentences summarizing the article based upon the information above using professional APA writing style):
The authors conducted a randomized control trial with 185 patients undergoing elective surgery requiring neuromuscular blocking and monitoring. The study aimed to determine the incidence of post-operative residual paralysis, defined as a train-of-four ratio (TOFR) less than 0.9, and post-operative hypoxemia when using quantitative compared to qualitative monitoring. The participants were randomized into either a quantitative group, which required a TOFR of at least 0.8 prior to extubation, and a qualitative group that relied on subjective measured of TOFR and clinical signs to assess readiness. The study found that qualitative monitoring led to a higher incidence of post-operative residual paralysis than quantitative monitoring. Additionally, qualitative monitoring resulted in severe blockade, TOFR less than or equal to 0.7, more often than quantitative monitoring. The patients in the qualitative monitoring group also had lower oxygen saturation, a higher incidence of severe hypoxemia, and more frequent interventions performed by the anesthetist to maintain a patent airway on their transport to the post-anesthesia care unit (PACU).

Thematic Analysis/Key Themes or FSP related significance:
1. Quantitative monitoring resulted in less post-operative residual paralysis.

2. Quantitative monitoring resulted in less adverse effects of post-operative residual paralysis (i.e. hypoxemia and airway obstruction). **3.** Patients with neuromuscular, hepatic, and renal disease were excluded from the study. **4.** Level II evidence

Appendix A: Evidence Review Worksheet Assignment C								
APA Citation: Samet, A., Capron, F., Alla, F., Meistelman, C., & Fuchs-Buder, T. (2005). Single acceleromyographic train-of-four, 100-hertz tetanus or double-burst stimulation: Which test performs better to detect residual paralysis? *Anesthesiology*, *102*(1), 51–56. https://doi.org/10.1097/00000542-200501000-00011								
Conceptual Framework or Model	***Design or Method***	***Sample & Setting***	***Major Variables Studied & their Definitions, if any***	***Outcome Measurement(s)***	***Data Analysis***	***Findings***	***Level of Evidence***	***Quality of Evidence: Critical Worth to Practice***
Theoretical basis for the study: N/A	Quasi-experimental design: Patients were allocated into two groups: 40 patients assessing the study's primary aim and 25 patients assessing the secondary aim. In both groups, the anesthesia technique was standardized across all patients, and the providers assessing the neuromuscular monitoring tests were not involved in the care. - The primary group had mechanomyography (MMG) set up on one arm to measure recovery from neuromuscular blockers. On the secondary arm, the patient had acceleromyography (AMG), double-burst stimulation (DBS), and 100 Hz-5s tetanus performed on it. The	**Number of Characteristics:** 65 adult patients American Society of Anesthesiologists class I-III scheduled for elective surgery under general anesthesia with tracheal intubation **Exclusion Criteria:** Neuromuscular, hepatic, or renal disease, abnormal airway anatomy, deviation from ideal body mass ≥ 25%, pregnancy, a medication that influences neuromuscular blockade, or allergy to the	**Independent variables:** - Single AMG stimulation - DBS - 100 Hz, 5s tetanus stimulation **Dependent variables:** - AMG TOFR - Degree of fade with DBS and 100 Hz, 5s tetanus - AMG TOFR compared to MMG TOFR	- The primary outcome of this study was to assess the performance of acceleromyography in detecting residual paralysis postoperatively compared to traditional qualitative methods (DBS and 100 Hz-5s tetanus). - The secondary aim of this study was to assess if uncalibrated acceleromyography can predict the time interval until full neuromuscular recovery	- Data were expressed as mean SD or mean and 95% confidence interval (CI) - Sensitivity, specificity, and negative and positive predictive values of double-burst stimulation, punctual acceleromyographic train-of-four, and 100-Hz 5-s tetanus presented as percentage and 95% confidence interval. **Qualitative analysis, if any:**	- 9/40 had no residual paralysis when neuromuscular recovery was assessed (MMG TOFR ≥0.9), but simultaneous evaluation by DBS, a single AMG TOF, and 100 Hz, 5-s tetanus suggested complete neuromuscular recovery in 31, 17, and 13 patients, respectively. - DBS, single acceleromyographic TOF, and 100 Hz, 5-s tetanus revealed false negative tests in 22, nine, and eight patients, respectively - The sensitivity of DBS, single AMG TOFR and 100-Hz, 5-s tetanus to detect an MMG TOFR ≥0.9 were 29% (95% CI, 13–45%), 70% (95% CI, 54 – 86%), and 74% (95% CI, 59–89%), respectively.	III	**Strengths:** The anesthesia process was standardized across all patients, limiting the interference of provider personal preference. Additionally, the results were obtained by independent providers not involved in the care, increasing the integrity of their observations. **Limitations:** This study was a quasi-experimental design which does not randomize the participants. **Risk or harm if implemented:** N/A **Feasibility of use in the project practice area:** The study answers the question set forth by the PICOT. However, it is a lower strength level of evidence. The results cannot be ignored, although. Additionally, the study excluded the “high-risk” patients as defined in the PICOT question.

	secondary arms tests were performed without awareness of the actual level of recovery. - The secondary group had AMG and MMG placed on opposite arms and synchronized. Upon assessment of neuromuscular functioning, both devices were used until MMG resulted in a train-of-four ratio (TOFR) >0.9.	drugs in the study **Attrition:** N/A **Setting:** University Hospital in France				- The specificity of these three tests were 100% (95% CI, 100 – 100%), 88% (95% CI, 67–100%), and 55% (95% CI, 23– 88%), respectively. - The negative predictive values were 29% (95% CI, 13–45%), 47% (95% CI, 23–71%), and 38% (95% CI, 12–64%), respectively - The positive predictive values of the three tests were 100% (95% CI, 100–100%), 95% (95% CI, 86–100%), and 85% (95% CI, 72–99%), respectively - When the uncalibrated AMG TOFR was 0.6, the MMG TOFR ≥0.9 occurred within 16 min (95% CI, 13.5–17.8 min). - At AMG ratios of 0.7, 0.8, and 0.9 this time interval was 12.5 min (95% CI, 10.2–14.8 min), 8 min (95% CI, 6.1–9.9 min), and 4 min (95% CI, 2.7–5.8 min), respectively - AMG can detect RP better than traditional,		

						qualitative tests of RP (DBS, and 100 Hz tetanus). - AMG cannot distinguish low levels of RP with accuracy - Uncalibrated AMG may be a valuable tool to predict the time needed to attain MMG TOFR >0.9		

Will complete this in Assignment E

Annotated Bibliography statement (may be several sentences summarizing the article based upon the information above using professional APA writing style):
The authors conducted a quasi-experimental study with 65 patients to determine the ability of acceleromyography to detect residual paralysis compared to qualitative methods, such as double-burst stimulus (DBS) and 100-Hz five second tetanus. Additionally, acceleromyography was compared to mechanomyography to determine if uncalibrated acceleromyography could accurately predict the time interval needed until full neuromuscular recovery. The study determined that acceleromyography is able to detect residual paralysis, a train-of-four ratio less than 0.9, better than the qualitative methods tested. Although, acceleromyography cannot distinguish low levels of residual paralysis with accuracy. Furthermore, uncalibrated acceleromyography may be able to predict the time interval needed to obtain full neuromuscular recovery. However, this study did not produce any guidelines for measuring said interval.

Thematic Analysis/Key Themes or FSP related significance:
1. Acceleromyography can detect residual paralysis better than qualitative tests.
2. Acceleromyography cannot detect low levels of residual paralysis accurately.
3. Patients with neuromuscular, hepatic, and renal disease were excluded from the study.
4. Level III evidence

Appendix A: Evidence Review Worksheet Assignment C								
APA Citation: Wardhana, A., Kurniawaty, J., & Uyun, Y. (2019). Optimised reversal without train-of-four monitoring versus reversal using quantitative train-of-four monitoring: An equivalence study. *Indian Journal of Anaesthesia*, *63*(5), 361. https://doi.org/10.4103/ija.ija_94_19								
Conceptual Framework or Model	***Design or Method***	***Sample & Setting***	***Major Variables Studied & their Definitions, if any***	***Outcome Measurement(s)***	***Data Analysis***	***Findings***	***Level of Evidence***	***Quality of Evidence: Critical Worth to Practice***
Theoretical basis for the study: N/A	Randomized control trial: patients were randomized based on stratification and type of surgery to a group using no TOF monitoring (group A) and a group using quantitative train-of-four (TOF) monitoring (group B). The allocated testing group was provided in a sealed envelope once the patient entered the operating room (OR). Group A was assessed for reversal based on spontaneous breathing efforts. Group B was assessed for reversal according to the quantitative train-of-four ratio (TOFR).	**Number of Characteristics:** 80 patients were eligible for the study. The patients were American Society of Anesthesiologist class I-II, aged 18-60 years, and undergoing non-head/neck surgery undergoing general anesthesia with intubation **Exclusion Criteria:** elective surgery <1 h duration, awake extubation or post-surgery intensive care admission, body mass index >35, hepatic disease, renal insufficiency, neuromuscular disease, consumption of drugs known to affect neuromuscular transmission, contraindications to neostigmine and atropine sulfate, a history of hypersensitivity or allergic to the anesthetic agent given, and difficulty accessing the	**Independent variables:** - Absence of TOF monitoring (spontaneous breathing as the assessment) - Quantitative TOF monitoring **Dependent variables:** - TOFR > 0.9 in the recovery room	- The primary outcome was the proportion of subjects who have residual paralysis in the recovery room based on the threshold TOFR <0.90 in both groups	- Data were expressed in terms of numbers and percentages, medians and ranges, and mean and standard deviations. - The data between the two groups were analyzed for differences using independent *t*-tests for numerical data and Fisher's exact tests for categorical data. - Data were analyzed using SPSS 24 software computer program	- The TOF ratio in the recovery room also did not differ between the two groups (mean difference = −2.58; $P = 0.053$). - The reversal-extubation time in group A was longer than in group B (mean difference = 5.08 min; $P = 0.002$) - Six cases of residual paralysis in the recovery room were found in group A, whereas one case occurred in group B (16.7 versus 2.8%). - There were no significant differences in the proportion of residual paralysis in the recovery room in both groups ($P = 0.107$). - The absolute difference in the	II	**Strengths:** The study was a randomized control trial which is a high level of evidence. The **Limitations:** The ages of the subjects were different in each group. There were participants who did not receive controlled ventilation. The extremities that TOF was measured on were not kept in a standardized range. Additionally, the TOF was not normalized. Lastly, the study did not determine superiority of reversal with and without TOF monitoring. **Risk or harm if implemented:** N/A **Feasibility of use in the project practice area:** The study excluded patients defined as "high-risk" by the PICOT question. Additionally, the comparison of the study was between no

		TOF measuring device in the ulnar nerve **Attrition:** Two patients were not extubated in the OR and six had their anesthetic gas switched from the standard protocol. Both categories of patients were excluded **Setting:** Indonesian Hospital				proportion of residual paralysis in the recovery room was 13.9% (95% confidence interval (CI): 1–27.2%) - Reversal without TOF monitoring was not equivalent to reversal with quantitative TOF monitoring.		TOF monitoring and quantitative TOF monitoring. This differs from the "traditional" TOF monitoring described in the PICOT. However, the study represents a superiority amongst using quantitative monitoring.

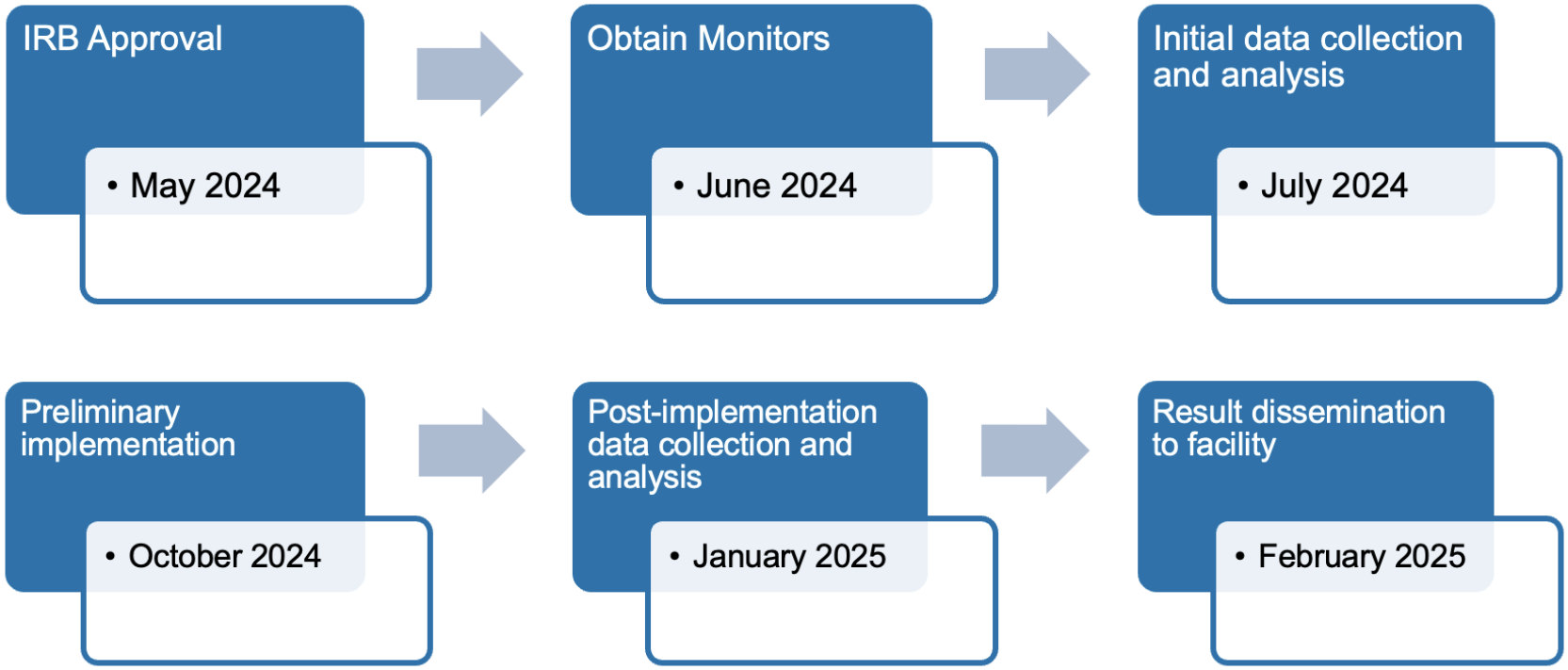
Will complete this in Assignment E

Annotated Bibliography statement (may be several sentences summarizing the article based upon the information above using professional APA writing style):
The authors conducted a randomized control trial with 80 patients undergoing general anesthesia with tracheal intubation. The study aimed to determine the incidence of post-operative residual paralysis, defined as a train-of-four ratio less than 0.9, when using quantitative monitoring versus no monitoring with spontaneous breathing as an indicator for tracheal extubation. The study results showed there were more cases of residual paralysis in the post-anesthesia care unit (PACU) when no monitoring was used, and less cases of residual paralysis when quantitative monitoring was used. Additionally, the study claims an optimized reversal strategy was not as effective without monitoring as opposed to with quantitative monitoring.

Thematic Analysis/Key Themes or FSP related significance:
1. Quantitative monitoring resulted in less residual paralysis than no monitoring.
2. A reversal strategy based on quantitative monitoring is superior to a strategy based on no monitoring.
3. There was no qualitative neuromuscular monitoring included in the randomized control trial.
4. Patients with neuromuscular, hepatic, and renal disease were excluded from the study.
5. Level II evidence

Appendix F

Timeline for Implementation



Appendix G

Final Scholarly Project Budget

Product	Cost	Amount	**Total**
Stimpod NMS 450x	**$1,995**	**29**	**$57,855**
Stimpod NMS 450x Electrodes	**$220/box of 10**	**10**	**$2,200**
EMR Communication Cable	**$400**	**29**	**$11,600**
CRNA Training	**$118/hour**	**1 hour of training x 30 CRNAs**	**$3,540**
Anesthesiologist Training	**$230/hour**	**1 hour of training x 20 MDAs**	**$4,600**
			$79,795