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Universal quantitative neuromuscular blockade monitoring at an academic medical center—A multimodal analysis of the potential impact on clinical outcomes and total cost of care

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ABSTRACT

Background: Quantitative train-of-four monitoring is not currently the standard of care when using neuromuscular blockade, although it has the potential to eliminate the complications of residual neuromuscular blockade. There are major costs associated with the complications of residual neuromuscular blockade as well as the purchase of quantitative train-of-four monitors. The aim of this study was to determine the cost effectiveness of universal quantitative train-of-four ratio monitoring as it pertains to purchase and use of quantitative train-offour monitors in comparison with potential costs of managing possible complications of residual neuromuscular blockade such as reintubation and pneumonia.

Methods: This observational study was conducted by the anesthesiology service for an urban academic medical center. All patients included were undergoing general endotracheal anesthesia with the use of neuromuscular blocking agents who were extubated at the end of their procedure. Qualitative and quantitative train-of-four ratio monitoring prior to extubation were compared to estimate the local incidence of residual post-operative neuromuscular blockade. The hospital electronic medical record and financial database were used to estimate the number of patients at risk for post-operative pneumonia or re-intubation, as well as the marginal costs associated with these complications. The incidence of residual post-operative neuromuscular blockade at the time of extubation was determined. The variable costs of care for patients who did or did not suffer either pneumonia or re-intubation in the postoperative period was compared to the annual cost of universal quantitative train-of-four ratio monitoring.

Results: A sensitivity analysis demonstrated that universal quantitative train-of-four ratio monitoring would result in a net cost savings for a broad range of efficacy estimates with regard to the reduction of post-operative pulmonary complications.

Conclusions: Introduction of universal quantitative train-of-four ratio monitoring may be justified based solely on the potential institutional cost savings.

1. Introduction

In a consensus statement on the perioperative use of neuromuscular blockade (NMB) monitoring published in 2018 an expert panel recommended that a quantitative technique should be used whenever a non-depolarizing NMB agent is administered.¹ This recommendation was based in part on the fact that widely employed qualitative NMB monitors do not allow detection of clinically meaningful residual NMB. It is known that experienced professionals are unable to discriminate between train-of-four ratio (TOFR) values greater than 0.4 when using

qualitative NMB monitors.^{2,3} Despite this limitation of qualitative NMB monitoring, quantitative techniques are not yet recommended as standard of care in the United States.⁴ The limited data available indicate that quantitative monitors remain inaccessible in most clinical settings and even the use of qualitative NMB monitoring is not universal.^{5,6}

The magnitude of the resulting deficiency in clinical care is concerning. Recent studies have documented an incidence of residual postoperative NMB as high as 65 percent with traditional anesthetic practices.^{7,8} Patient characteristics such as male gender, high BMI, and prolonged surgery may be associated with residual NMB.^{9,10} Practice

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characteristics such as routine reliance on clinical signs of recovery, monitoring of NMB at the facial nerve, or community practice settings have also been associated with an increased risk of incomplete recovery from NMB at the time of extubation.^{3,11,12}

The occurrence of sub-clinical residual NMB in the early postoperative period may significantly increase the incidence of pulmonary complications.^{9,10,13–18} Although the absolute magnitude of this increased risk may be small for an individual patient, the frequency of NMB use during anesthetic care results in substantial morbidity and mortality when considering the entire population of patients involved. Each potentially preventable post-operative pneumonia or reintubation increases hospital length of stay or demand for intensive care unit beds. A low incidence of complications each of which result in high resource utilization will result in large avoidable costs. Thus, the issue of residual post-operative NMB presents an opportunity for meaningful practice improvement both from a clinical and financial perspective as the medical profession attempts to implement six-sigma levels of reliability.

A significant objection to the implementation of quantitative NMB monitoring is the cost. The cost of acquisition for new quantitative monitors is approximately 10 times higher than for traditional qualitative devices (\$2000 versus \$200). Some quantitative monitors also require single patient use disposable components. However, as described above, these costs may be more than offset by savings achieved from a reduction in post-operative complication rates.

In the current fiscal environment, any change promoted in the name of care improvement should be studied meticulously. A robust clinical practice analysis combined with accurate cost accounting should reveal a net financial benefit at the institutional level for most initiatives that improve patient outcomes as overall resource utilization is reduced. Such a global perspective on the cost of care may be critical to winning support from the organization for the necessary investment of capital.

No data are currently available describing the cost effectiveness of quantitative NMB during routine clinical use. This report uses a multimodal analysis to estimate the potential clinical and financial impact of deploying universal quantitative neuromuscular monitoring at a large urban academic medical center located in the United States.

2. Methods

The study design was approved by the Temple University Institutional Review Board. The study was determined not to involve human subjects research and did not require formal review nor patient consent. The study and this report both adhere to the CHEERS reporting recommendations for economic evaluations under the EQUATOR guidelines.

As part of a performance improvement initiative, one-hundred patients undergoing elective surgery under general endotracheal anesthesia (GETA) requiring administration of a nondepolarizing NMB agent were evaluated during July and August of 2019. Each was assessed with an EMG-based quantitative train-of-four ratio (qTOFR) measurement just prior to extubation. During the antecedent surgical procedure, the clinical anesthesia team responsible for each patient's care used a qualitative TOF monitor to manage NMB according to their own standard practice. A qTOFR measurement was only obtained once the clinical care team declared the NMB to be fully reversed and the patient ready for emergence and extubation. All qTOFR measurements were made under general anesthesia and prior to the resumption of spontaneous patient movement. The results of this PI project were used to estimate the current extent of sub-clinical residual NMB at Temple University Hospital (TUH).

Phase two of the analysis determined the specific contemporary incidence of post-operative pulmonary complications at TUH. The TUH National Surgical Quality Improvement Program (NSQIP) database was queried for patients who underwent surgery utilizing GETA during the calendar years of 2017 and 2018. Any patients who suffered a postoperative pneumonia not present at the time of surgery or an

Table 1

Quantitative train-of-four results just prior to extubation for patients undergoing elective surgery.

T4:T1 Ratio	Patients ($N = 100$)
0.00 - 0.10	1
0.11 - 0.20	3
0.21 - 0.30	2
0.31 - 0.40	5
0.41 - 0.50	7
0.51 - 0.60	7
0.61 - 0.70	6
0.71 - 0.80	13
0.81 - 0.90	16
0.91 - 1.00	40

Table 2

Complications and variable costs of care from the TUH NSQIP and financial databases.

	Neither Complication		Pneumonia and / or Reintubation	
Service	N	Avg Variable Cost of Care	Ν	Avg Variable Cost of Care
Colorectal	165	\$18,832	14	\$70,642
General	322	\$10,254	14	\$22,502
Gynecology	155	\$5817	2	\$34,336
Neurosurgery	87	\$22,081	4	\$51,681
Orthopedics	254	\$14,664	3	\$19,599
Plastics	61	\$11,260	2	\$106,340
Urology	288	\$12,359	7	\$38,284
Vascular	302	\$21,613	16	\$64,790
Total	1634	\$14,522	62	\$50,895

unanticipated reintubation during hospitalization were then identified within this subset of NSQIP patients.

Phase three of the analysis estimated the marginal costs associated with the occurrence of a post-operative pulmonary complication. Each patient identified in the initial NSQIP search was matched with their respective record in the hospital's business intelligence cost accounting database. This database is maintained by the institution in order to provide financial support to strategic operational decisions. Within the database all direct non-salary costs involved in a patient's care (pharmaceuticals, blood products, disposable supplies, etc.) are allocated to that specific patient. Direct salary costs attributable to patient care (nurses, technicians) are treated similarly. Indirect costs representing managerial and administrative staff as well as institutional infrastructure are attributed to individual patients based on length and location of hospital stay. The costs associated with each admission were summed and then used to determine the difference between the total cost of care for surgical patients at TUH with or without a post-operative pulmonary complication.

Finally, a sensitivity analysis was performed to compare the cost of universal qTOFR monitoring with the potential range of cost savings that could potentially be achieved through a reduced incidence of postoperative pulmonary complications.

3. Results

The incidence of residual NMB at the time of extubation was found to be 60%, using a qTOFR result of less than 0.9 as the threshold (Table 1). Because these results were obtained while completing a performance improvement project no information was collected to allow subsequent patient identification or assessment of post-operative complications amongst this cohort.

The NSQIP database search identified 1791 abstracted files of patients who had undergone GETA for a surgical procedure during 2017 or 2018. Of these, 45 (2.5%) were diagnosed with post-operative pneumonia and 48 (2.7%) required post-operative reintubation. Overall, one

Table 3

Annual cost of implementing universal qTOFR monitoring at TUH.

Category	Unit Cost	Volume Required	Annual Cost
Disposables Monitor Total	\$20 \$2000	7500 30	\$150,000 \$12,000* \$162,000

Depreciated over an estimated 5-year usable life span.

or more major post-operative pulmonary complications occurred in 76 individuals (4.2%).

Records were identified within the institutional accounting database for 1634 (95%) of the NSQIP patients without a post-operative complication, and 62 (82%) of the patients with a post-operative pulmonary complication. The average variable cost of care for patients

Y = (5.4%)*(1/3) = 1.8%

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without complications was \$14,522, and for patients suffering pneumonia and / or reintubation was \$50,895 (Table 2). The marginal cost associated with a post-operative pulmonary complication following GETA at TUH during this period was calculated as \$36,372.

Reports available through the institutional electronic medical record revealed that roughly 7500 anesthetics each year at TUH require GETA and reversal of NMB. From the random assessment of qTOFR prior to extubation it was estimated that approximately 4500 TUH surgical patients (60% of 7500) each year suffer from residual NMB after extubation and are exposed to an increased risk of post-operative pulmonary complications.

Given the total number of patients at risk (4500) and the measured incidence of either post-operative pneumonia or reintubation (4.2%), it can be estimated that 189 TUH patients each year suffer major post-op respiratory morbidity after GETA while also experiencing residual

<u>Let</u> :	X = proportion of patients with residual NMB who suffer a post-operative complication	
	Y = proportion of patients without residual NMB who suffer a post-operative complication	
	C = proportion of total population of patients who suffer a post-operative complication	

<u>Given</u> :	roughly 2/3 of the patient population experiences residual NMB post-operatively Y = X*(1/3), from the historical literature C = 4.2%, at TUH
<u>Then</u> :	$C = X^{*}(2/3) + Y^{*}(1/3)$ $C = X^{*}(2/3) + X^{*}(1/9)$ $C = X^{*}(7/9)$ $X = (4.2\%)^{*}(9/7) = 5.4\%$

If residual NMB is eliminated, the rate of post-op complications for the entire population will fall to equal 'Y' (1.8%). This would represent a 66% reduction from the baseline rate of 5.4% amongst the proportion of the population who previously experienced residual NMB post-operatively



Fig. 1. Derivation of maximum potential reduction in post-operative pulmonary complication rate if residual NMB is eliminated.

Fig. 2. Annual institutional costs under the current state, with the maximum projected reduction in post-op pulmonary complications, and under breakeven conditions.

NMB. Given a marginal cost of \$36,372 per patient, the total annual cost of such complications is estimated to be \$6.9 million.

The cost to TUH of universally deploying EMG-based quantitative NMB monitoring would include both capital costs and the annual costs of disposable supplies. The acquisition cost of 30 monitors would be approximately \$60,000, or \$12,000 per year when depreciated over an anticipated 5-year life span. Each patient monitored with the EMG-based quantitative NMB monitor employed in this study required a disposable stimulation and monitoring lead, with a unit cost of \$20. The disposable supplies required to monitor 7500 patients each year would cost \$150,000. The annual cost of implementing universal qTOFR monitoring would therefore total approximately \$162,000 (Table 3).

4. Discussion

Although highly dependent on the practice and patient population in question, evidence suggests that residual NMB at the time of extubation may increase the risk of post-operative pulmonary complications or intensive care unit admission up to 3 times that for patients without residual NMB.^{13–18} As a corollary, it may be deduced that the incidence of post-operative pulmonary complications and associated costs may be reduced by approximately 66% amongst those patients experiencing residual NMB if the phenomenon could be eliminated (Fig. 1).

According to the data presented above the maximum potential yearly cost savings for TUH from eliminating post-operative pulmonary complications associated with residual NMB would be \$4.6 million dollars (66% x \$6.9 million). This compares very favorably with an annual cost of implementing universal qTOFR monitoring of \$162,000.

Alternatively, if the institution of EMG-based quantitative NMB monitoring was able to prevent a minimum of 5 (2.6%) of the anticipated 189 patients expected to suffer major post-operative pulmonary complications each year in the presence of residual NMB, there would be no net cost to the institution from this quality improvement initiative (Fig. 2).

This multimodal analysis depends on published reports to estimate the effect of residual NMB on the incidence of pulmonary complications in surgical patients. The sensitivity analysis performed suggests that cost benefits persist for a wide range of improved clinical outcomes. Nonetheless, if universal qTOFR monitoring were implemented it would be important to continue to monitor a variety of process and outcome metrics to ensure that the expected benefits were achieved. Such metrics should include: rate of qTOFR use, rate of compliance with 90% threshold for extubation, rate of post-operative pneumonia, and rate of post-operative reintubation. In addition, ongoing monitoring for operational effects related to this systematic change should be undertaken, such as a significant change in the time from procedure end to extubation and the overall utilization and cost of NMB reversal agents.

The cost data used to perform this analysis are specific to Temple University Hospital. The precise cost for implementing universal qTOFR monitoring is dependent on the technology employed. The hardware acquisition price for other institutions may differ, and ongoing costs for disposable supplies may or may not be required depending on the type of quantitative monitor selected. The costs of hospital-based care, and of treating complications, may vary significantly in other geographic regions or under other organizational structures. However, given the robust nature of the cost savings identified even moderate variations in these costs are unlikely to change the favorable financial results of implementing universal quantitative NMB monitoring.

This analysis describes the potential clinical and financial benefits available from the elimination of residual NMB for the academic medical center studied. However, both of these positive effects depend on the effective implementation of a change in anesthetic practice. Access to new technology alone would be insufficient to achieve this objective.^{19,20} Educational programs would need to be provided to clinical staff emphasizing the risks of residual NMB. In addition, the public reporting and regular discussion of performance measures related to the

avoidance of residual NMB should be implemented.

5. Conclusion

The universal deployment of qTOFR monitoring has the potential to improve clinical outcomes by eliminating the risk of postoperative residual NMB and associated respiratory complications. This analysis suggests a robust cost benefit for the academic medical center studied from such a change, despite the expense associated with the technology. Further studies are needed to confirm the anticipated financial and clinical benefits after implementation.

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Declaration of Competing Interest

The authors report no conflicts of interest.

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