Section: Anaesthesia

Original Research Article

CAPNOGRAPHIC CURARE NOTCH AS AN INDICATOR OF NEUROMUSCULAR RECOVERY: INSIGHTS FROM TRAIN-OF-FOUR MONITORING IN VENTILATED PATIENTS

Sanika Shukla[1], Anil Kumar Verma[2], Neha Mishra[3]

[1]*Junior Resident, Department of Anaesthesia, GSVM Kanpur, Uttar Pradesh, India.*
[2]*Professor, Department of Anaesthesia, GSVM Kanpur, Uttar Pradesh, India.*
[3]*Assistant Professor, Department of Anaesthesia, GSVM Kanpur, Uttar Pradesh, India.*

Received *: 10/10/2024*
Received in revised form *: 03/12/2024*
Accepted *: 18/12/2024*

Corresponding Author:
Dr. Sanika Shukla,
Junior Resident, Department of Anaesthesia, GSVM Kanpur, Uttar Pradesh, India.
Email: drsanikashukla@gmail.com

DOI: 10.70034/ijmedph.2024.4.220

Source of Support: Nil,
Conflict of Interest: None declared

Int J Med Pub Health
2024; 14 (4); 1194-1198

ABSTRACT

Background: Train-of-Four (TOF) monitoring is a commonly used method to assess neuromuscular blockade and recovery during surgeries involving neuromuscular blocking agents (NMBAs). However, in resource-limited settings, TOF monitors may not be readily available. Capnography, typically used for ventilation monitoring, has shown potential for indicating early recovery through curare notches on the waveform. **Objective:** This study aims to evaluate the relationship between TOF count and the appearance of curare notches in the capnography waveform, indicating the onset of spontaneous respiration. It further explores whether curare notches could serve as a reliable alternative for neuromuscular recovery monitoring in facilities without TOF monitors.

Material and Methods: A prospective observational study was conducted in a tertiary care hospital in India, involving ten patients undergoing surgery under general anesthesia. TOF counts were measured at the adductor pollicis muscle, while the presence of curare notches in capnography waveforms was documented. Preoperative, intraoperative, and post-extubation vital signs were recorded. Pearson correlation analysis was used to evaluate the relationship between curare notches, TOF counts, and recovery time after sugammadex administration.

Results: A moderate positive correlation (r=0.612, p=0.060) was observed between TOF counts and curare notches. A weak negative correlation (r=-0.248, p=0.490) was found between TOF counts and recovery time. Curare notches appeared at low TOF counts, indicating early diaphragmatic recovery before full peripheral muscle recovery.

Conclusion: Capnography, through curare notch observation, can assist in assessing neuromuscular recovery in the absence of TOF monitors. Combined with clinical signs, curare notches offer a practical alternative for resource-limited settings.

Key Words: Neuromuscular Blockade; Capnography; Train-of-Four Stimulation; Sugammadex; Postoperative Complications.

INTRODUCTION

Neuromuscular monitoring is crucial for ensuring optimal patient care during surgery, particularly when neuromuscular blocking agents (NMBAs) are used to induce paralysis for intubation and controlled ventilation. The Train-of-Four (TOF) count, assessed via peripheral nerve stimulation, is the established standard for measuring the depth of neuromuscular blockade and recovery. TOF count measures the extent of receptor blockade by evaluating muscle twitches in response to electrical stimuli. However, in many resource-limited settings, access to TOF monitors is scarce, which necessitates

the need for alternative methods to assess neuromuscular recovery.[1,2,3]

Residual neuromuscular blockade, if undetected, has been linked to postoperative respiratory complications, such as hypoxia and airway obstruction, which can result from incomplete recovery of muscle function.[4,5,6] While TOF monitoring is a standard, capnography—a tool typically used to monitor ventilation—has gained attention as a potential adjunct for assessing neuromuscular recovery. The appearance of curare notches on the capnography waveform has been linked to the return of diaphragmatic activity and spontaneous respiration following NMBA administration.[7] The relationship between curare notches and TOF counts may offer a practical, non-invasive alternative for assessing neuromuscular recovery in facilities where TOF monitoring is not available.

This study explores the correlation between TOF counts and curare notches, with a focus on whether curare notches can serve as a reliable indicator of neuromuscular recovery in mechanically ventilated patients. Additionally, the study assesses the relationship between TOF counts, curare notches, and the time to complete neuromuscular reversal following the administration of sugammadex.

MATERIALS AND METHODS

Study Design and Setting

A prospective observational study was conducted in the Department of Anesthesia at a tertiary care hospital in the northern region of India following ethical approval by the institutional ethical committee. All participants were thoroughly informed about the study, and written consent was obtained before the commencement of any study procedures. The study aimed to correlate the level of neuromuscular block, measured using the Train-of-Four (TOF) count/ratio, with the initiation of respiration indicated by the presence of curare notches in the capnography waveform in the presence of clinical signs of reversal such as head lift, hand grip, spontaneous eye opening, and following verbal commands in mechanically ventilated patients undergoing surgery.

Patient Selection

Among the patients cleared for surgery following a comprehensive pre-anesthetic evaluation, a total of ten patients of both sexes were enrolled in the study. These patients were aged 18 years or older and classified as American Society of Anesthesiologists (ASA) Grade 1 or 2. All participants were scheduled for elective surgical procedures to be conducted under general anesthesia, incorporating the use of neuromuscular blocking agents (NMBAs). Exclusion criteria were rigorously applied, excluding individuals with known or suspected allergies to anesthetic agents, a history of drug use that might interact with NMBAs, existing electrolyte imbalances, critical liver or kidney diseases, metabolic disorders, current pregnancy, breastfeeding status, or a history suggestive of malignant hyperthermia.

Anesthetic Protocol

All patients were premedicated with 0.25 mg of oral alprazolam a night before the induction of anesthesia for anxiolysis. Standard ASA monitors such as heart rate, BP, SpO2 and temperature were recorded pre-operatively. After three minutes of preoxygenation period, anesthesia induction was achieved with propofol (target concentration of 3 µg/ml over three minutes) and 100 mcg of fentanyl as an analgesic. Once the verbal response to commands was lost, assisted ventilation with 100% oxygen by facemask was started. After administering the appropriate bolus dose of vecuronium (0.08 to 0.1 mg/kg), a non-depolarizing neuromuscular blocking agent (NMBA), patients were put on endotracheal intubation. Normocapnic ventilation was established using a Fabius GS ventilator (Dräger Medical AG & Co., Lübeck, Germany). Anesthesia was maintained with oxygen, air, propofol target-controlled infusion (25 mcg/kg/min), and vecuronium, maintenance dose of 0.8 to 1.2 µg/kg/min. During maintenance of anesthesia, end-tidal CO_2 was kept between 35 and 45 mmHg.

Monitoring and Data Collection

Routine standard monitoring including electrocardiography, pulse oximetry, end-tidal CO_2 ($EtCO_2$), and non-invasive blood pressure assessment were systematically recorded preoperatively, intraoperatively, and post-extubation. Intraoperative temperature management was achieved using radiant heat from a thermal ceiling, maintaining an ambient temperature of 24°C.

The TOF-Watch SXR gadget (Merck Sharp & Dohme Corp., Glostrup, Denmark) was used to continually monitor neuromuscular function at the adductor pollicis muscle. Over the ulnar nerve at the wrist, two surface electrodes (CleartrodeTM, ConMed®, Utica, NY, USA) were applied on a clean skin. By moving the piezoelectric transducer or fastening the wrist, recalibration was carried out if the initial train-of-four ratio (TFR) and T1 response were less than 95% or greater than 105%. Until the anesthesia ended, the TOF mode of supramaximal stimulation (0.2 ms duration, frequency 2 Hz, lasting 2 seconds) was administered at 15-second intervals.

Curare notches were tracked through capnography, with a particular focus on the appearance of the first, second, and third notches that were correlated with TOF count and ratio. At the surgery's conclusion, the number of simultaneous curare notches were documented, along with clinical signs of reversal with the corresponding TOF values. Following surgery, each patient received sugammadex at 4.0 mg/kg upon observing the initiation of spontaneous respiration, marked by the presence of curare

notches. Extubation was conducted after the appearance of clinical signs of reversal, and the time required for complete reversal was recorded.

Statistical Analysis

Pearson correlation was employed to evaluate the relationships between TOF counts, curare notches, and time to complete neuromuscular reversal. Descriptive statistics, including means and standard deviations, were used to summarise demographic characteristics and vital signs. Statistical significance was set at $p<0.05$.

RESULTS

Patient Demographics and Vital Signs

A total of 10 patients were enrolled in this study, comprising six males and four females. The mean age of the patients was 27.4 ± 7.8 years (19-41 years). All patients were classified as ASA Grade 1 or 2, indicating that they were generally healthy with no significant comorbidities that might have impacted the course of their surgery or recovery from neuromuscular blockade.

Vital signs were monitored across three phases: preoperatively, intraoperatively, and post-extubation, providing a comprehensive picture of the patient's hemodynamic stability. Preoperatively, the mean heart rate (HR) was 88.4 ± 21.2 bpm (beats per minute), reflecting baseline cardiovascular status. Intraoperatively, heart rates showed minimal variation, averaging 91.5 ± 15.3 bpm, indicating that patients remained stable under anesthesia. Post-extubation, the heart rate increased slightly to 101 ± 15 bpm, likely reflecting the body's physiological response to the cessation of anesthesia and the resumption of spontaneous respiration.

Mean arterial pressure (MAP) followed a similar pattern, with a preoperative average of 104 ± 12.1 mmHg, which dropped slightly intraoperatively to 98.5 ± 11.2 mmHg but remained within normal physiological ranges. Post-extubation, MAP increased modestly to 105 ± 8 mmHg. Oxygen saturation (SpO_2) was consistently maintained at or near 100% throughout the perioperative period, demonstrating the efficacy of controlled mechanical ventilation in maintaining adequate oxygenation.

TOF Count, Curare Notch and Time of complete recovery

Among the study population, we observed that out of ten cases, five cases showed only one curare notch while the other five had three consecutive curare notches. For each curare notch (maximum three consecutive) that was observed, TOF count values and recovery time (after the appearance of all clinical signs of reversal) were noted as shown in Table 1.

The mean time to complete neuromuscular reversal after sugammadex administration was 193.4 ± 50.2 seconds. It was observed that TOF count value varied from 0 to 3 and the recovery time ranged from 110 to 272 seconds. For cases with the appearance of only one curare notch, TOF count varied from 0 to 2 and recovery time ranged from 110 to 272 seconds. (Figure1A) For cases where three consecutive notches were observed, TOF count varied from 1 to 3 and recovery time ranged from 150 to 220 seconds. (Figure 1B) The recovery time trend showed that cases with higher TOF count (2 and 3) had shorter recovery time whereas lower TOF counts (0 and 1) were more variable and had longer recovery time. We observed a moderate positive correlation ($r=0.612$, $p=0.060$) between TOF count and curare notch appearance and a weak negative correlation ($r=-0.248$, $p=0.490$) between TOF count and time of complete reversal. In all the cases, the post-operative period was uneventful, and none of them showed any residual neuromuscular blockade.

Figure 1A: Capnography waveform showing the appearance of a single curare notch at a TOF count of 2

Figure 1B: Capnography waveform illustrating three simultaneous curare notches at a TOF count of 1

Table 1: No. of curare notches appeared, TOF count and recovery time in seconds

S No.	Curare Notch	TOF Count	Recovery Time (seconds)
1	1	0	126
2	3	3	208
3	1	2	110
4	3	2	150
5	1	0	230
6	1	0	272
7	3	1	210
8	3	1	180
9	3	2	220
10	1	1	210

DISCUSSION

This study explored the potential of using capnographic curare notches as indicators for neuromuscular recovery in patients undergoing surgery with neuromuscular blocking agents (NMBAs). The findings revealed a moderate positive correlation (r=0.612, p=0.060) between the presence of curare notches and TOF counts, suggesting that capnography could serve as a supplementary tool for monitoring neuromuscular recovery particularly in resource-limited settings which is supported by the literature as well that capnography can provide valuable, non-invasive feedback on wearing off of neuromuscular blockade and spontaneous respiration.[8,9,10]

Our results indicated that the appearance of curare notches on the capnogram often preceded a TOF count of 3, suggesting early recovery of diaphragmatic function. This aligns with the physiological basis of curare notches, which represent spontaneous diaphragmatic contractions as central respiratory muscles regain activity. Literature supports this mechanism; for example, Babik et al. describe how capnography can detect changes in the ventilation pattern due to diaphragmatic movements during recovery from neuromuscular blockade.[11] These findings suggest that in the absence of TOF monitors, capnography could help clinicians recognize early signs of recovery and adjust their timing for administering reversal agents like sugammadex.

Our study found that patients with higher TOF counts (2 or 3) had shorter recovery times following sugammadex administration, while lower TOF counts (0 and 1) were associated with more variable recovery times. These findings align with existing literature that emphasizes the importance of TOF monitoring for assessing comprehensive neuromuscular recovery. Naguib et al. highlight that reliance on non-quantitative assessments of neuromuscular recovery can increase the incidence of residual paralysis even when using effective reversal agents.[6] These observations suggest that while capnography can provide supplementary information, it cannot replace the specificity of TOF monitoring in ensuring complete recovery across all muscle groups before extubation. Previous studies, such as by Murphy et al., highlight that TOF ratios below 0.9 at the time of extubation are linked to significant postoperative respiratory complications, including hypoxemia and airway obstruction.[5]

In our study, none of our participants complained of any residual neuromuscular blockade but we had a small sample size of ten patients undergoing surgery under general anesthesia which demands a research with larger study population, includes both sexes and maybe a multicentric approach. Through this study, we can infer that capnography along with clinical signs of recovery acts as a robust framework for neuromuscular recovery monitoring. Therefore, combined approaches i.e., capnography used alongside simpler, more practical clinical signs, such as head-lift test or hand grip, could offer a viable alternative in settings lacking TOF monitors. Developing protocols that combine capnographic data with standard clinical assessments could help bridge the gap between resource-rich and resource-limited settings, ensuring better patient outcomes globally.

This study has limitations. The small sample size of ten patients limits the generalizability of our findings, and the single-center setting may not capture the variability of clinical practice across different environments. Additionally, our use of visual assessment for detecting curare notches could introduce observer bias, as interpretation of the capnogram may vary among clinicians. To enhance the accuracy of our findings, future research should include larger, multicenter trials with automated methods for curare notch detection to reduce subjectivity.

Looking forward, further research should explore integrated monitoring approaches combining capnography with additional clinical assessments to develop a comprehensive neuromuscular monitoring strategy for resource-limited settings. Babik et al. also suggests that capnographic assessments may be improved with adjustments considering individual patient variables such as compliance and resistance.[11] This combined or enhanced approach could be particularly valuable in global health contexts, where access to advanced neuromuscular monitoring technology is limited but patient safety remains a priority.

CONCLUSION

This study demonstrated that curare notches in capnography correlate moderately with TOF counts

and can serve as a supplementary tool for monitoring neuromuscular recovery, particularly in settings where access to advanced TOF monitoring is limited. In settings where TOF monitoring is unavailable, capnography should be used in conjunction with clinical assessments to support safer, more informed decisions. However, further research with larger sample sizes is required to validate the clinical utility of curare notches and to clarify their relationship with recovery time.

REFERENCES

1. Cook D, Simons DJ. Neuromuscular Blockade. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 [cited 2024 Oct 31]. Available from: http://www.ncbi.nlm.nih.gov/books/NBK538301/
2. StatPearls. Neuromuscular Blocking Agents - StatPearls - NCBI Bookshelf [Internet]. [cited 2024 Oct 31]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK537168/
3. Comparison of train-of-four count by anesthesia providers versus TOF-Watch SX: a prospective cohort study - ProQuest [Internet]. [cited 2024 Oct 28]. Available from: https://www.proquest.com/openview/1140de54c3e4833cee2694346743a3aa/1?pq-origsite=gscholar&cbl=326357
4. Baillard C, Gehan G, Reboul-Marty J, Larmignat P, Samama CM, Cupa M. Residual curarization in the recovery room after vecuronium. Br J Anaesth. 2000 Mar;84(3):394–5.
5. Murphy GS, Szokol JW, Marymont JH, Franklin M, Avram MJ, Vender JS. Residual paralysis at the time of tracheal extubation. AnesthAnalg. 2005 Jun;100(6):1840–5.
6. Naguib M, Brull SJ, Hunter JM, Kopman AF, Fülesdi B, Johnson KB, et al. Anesthesiologists' Overconfidence in Their Perceived Knowledge of Neuromuscular Monitoring and Its Relevance to All Aspects of Medical Practice: An International Survey. AnesthAnalg. 2019 Jun;128(6):1118–26.
7. Thieme E-Journals - AINS - Anästhesiologie · Intensivmedizin · Notfallmedizin · Schmerztherapie [Internet]. [cited 2024 Nov 3]. Available from:https://www.thieme-connect.de/products/ejournals/abstract/10.1055/s-2007-998940
8. Bissinger U, Lenz G, Reiter A, Albrecht T, Schorer R. Überwachung der neuromuskulärenFunktion: Kapnographie versus Relaxometrie. AnästhesiolIntensivmedNotfallmedSchmerzther. 1993 Oct;28(6):359–62.
9. Capnography: Principles and application in critical care medicine [Internet]. [cited 2024 Nov 3]. Available from:https://www.ijrc.in/abstractArticleContentBrowse/IJRC/31074/JPJ/fullText
10. Capnography/Capnometry During Mechanical Ventilation: 2011 | Respiratory Care [Internet]. [cited 2024 Nov 3]. Available from:https://rc.rcjournal.com/content/56/4/503
11. Babik B, Csorba Z, Czövek D, Mayr PN, Bogáts G, Peták F. Effects of respiratory mechanics on the capnogram phases: importance of dynamic compliance of the respiratory system. Crit Care. 2012 Oct; 16:1–0.