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Evaluation of Muscle Relaxation Efficacy in Typically Developing vs. Developmentally Delayed Pediatric Populations

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Abstract: ***Background:*** Muscle relaxation is an essential component of general anesthesia, ensuring optimal surgical conditions and patient safety, particularly in pediatric populations. However, the response to neuromuscular blocking agents (NMBAs) can vary significantly among children, especially those with underlying neurodevelopmental conditions. This study was undertaken to evaluate and compare the efficacy of muscle relaxation between typically developing children and those with developmental delay. ***Methods:*** This comparative observational study was conducted in the Department of Anesthesiology at Impact Masudul Haque Hospital, a tertiary care center in Chuadanga, over 18 months from January 2023 to June 2024. A total of 125 pediatric patients aged 2 to 12 years, undergoing elective surgeries under general anesthesia with planned use of muscle relaxants, were included. Statistical analysis was performed using SPSS version 26.0, with quantitative variables compared using an independent sample t-test and categorical variables analyzed using the Chi-square test, considering $p < 0.05$ as statistically significant. ***Result:*** In this study of 125 children, those with developmental delay required lower doses of muscle relaxants (0.08 ± 0.04 mg/kg vs. 0.12 ± 0.02 mg/kg; $p = 0.032$) and had a delayed onset of blockade (95.2 ± 14.8 s vs. 78.4 ± 12.5 s; $p < 0.001$) compared to typically developing children. Recovery time was significantly longer in the DD group (28.9 ± 6.7 min vs. 21.5 ± 5.4 min; $p < 0.001$), with more cases of prolonged recovery (>30 min) seen in DD children (36.0% vs. 12.0%; $p = 0.001$). ***Conclusion*:** This study demonstrates that children with developmental delay exhibit increased sensitivity to muscle relaxants, delayed onset of neuromuscular blockade, deeper blockade trends, and significantly prolonged recovery compared to typically developing children. These findings highlight the need for individualized anesthetic dosing, routine quantitative neuromuscular monitoring, and extended postoperative observation to enhance safety and optimize muscle relaxation efficacy in this vulnerable pediatric population.

Keywords: Muscle Relaxation, Typically Developing Children, Delayed Pediatric Populations, Neuromuscular Blocking Agents.

Original Research Article

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INTRODUCTION

Muscle relaxation plays a crucial role in paediatric clinical practice, particularly during surgical procedures, diagnostic interventions, and rehabilitation therapies. In paediatric anaesthesia, effective muscle relaxation facilitates optimal surgical conditions, ensures patient safety, and reduces the risk of intraoperative complications.[1] However, achieving consistent and predictable muscle relaxation remains a challenge, especially when considering variations between typically developing (TD) children and those with

developmental delays (DD).Developmental delay, encompassing global delays in motor, cognitive, language, and socio-emotional development, affects approximately 5-10% of children worldwide, with higher prevalence reported in low- and middle-income countries.[2,3] Children with DD, including conditions such as cerebral palsy, Down syndrome, and global developmental delay, often present with neuromuscular abnormalities such as spasticity, hypotonia, or dystonia, which can significantly alter their response to muscle relaxants and impact procedural outcomes.[4] Pharmacological muscle relaxation is primarily achieved through the administration of neuromuscular blocking agents (NMBAs), which inhibit acetylcholine at the neuromuscular junction, leading to reversible skeletal muscle paralysis.[5] However, studies have demonstrated that children with neuromuscular disorders or DD may exhibit increased sensitivity or resistance to NMBAs, leading to either prolonged recovery or inadequate muscle relaxation. For instance, research has highlighted altered pharmacokinetics and unpredictable neuromuscular responses to both depolarizing and non-depolarizing muscle relaxants in children with cerebral palsy and other forms of DD.[6]

Moreover, the accuracy and reliability of neuromuscular monitoring techniques such as train-of-four (TOF) stimulation and electromyography (EMG) are critical for titrating muscle relaxants in paediatric populations. Yet, evidence suggests that these monitoring modalities may yield variable results in children with DD due to underlying muscle pathology or altered neuromuscular transmission.[7] Such variability underscores the importance of individualized aesthetic management and highlights the need for comparative studies evaluating muscle relaxation efficacy in TD versus DD children. Beyond the operating room, muscle relaxation interventions are central to managing spasticity and improving motor function in children with DD. Pharmacological approaches, including botulinum toxin injections and oral muscle relaxants, alongside non-pharmacological strategies such as physiotherapy and stretching programs, have shown efficacy in reducing hypertonia and enhancing functional mobility.[8,9] However, treatment responses often differ between DD and TD populations, largely due to variations in muscle tone, neural control, and motor development. Despite the widespread use of muscle relaxation techniques in paediatric care, there remains a significant gap in the literature regarding the comparative evaluation of their efficacy between TD and DD populations. Most existing studies focus either on the pharmacodynamics of NMBAs in isolated conditions, such as cerebral palsy, or on general paediatric anaesthesia, without directly comparing these distinct groups.[10] A clearer understanding of these differences is essential for optimizing perioperative management, reducing complications, and enhancing therapeutic outcomes in children with Do this study aims to systematically evaluate the efficacy of muscle relaxation in TD versus DD paediatric populations by analysing pharmacological response patterns, neuromuscular monitoring parameters, and clinical outcomes. The findings are expected to guide clinicians in adopting tailored approaches for muscle relaxation in children with diverse neurodevelopmental profiles, ultimately improving patient safety and procedural success.

METHODS

This comparative observational study was conducted in the Department of Anesthesiology at Impact Masudul Haque Hospital, a tertiary care center in Chuadanga, over 18 months from January 2023 to June 2024. A total of 125 pediatric patients aged 2 to 12 years, undergoing elective surgeries under general anesthesia with planned use of muscle relaxants, were included. The participants were divided into two groups: 75 typically developing (TD) children and 50 children with developmental delay (DD), confirmed through clinical and neurodevelopmental assessment. Inclusion criteria were children aged 2–12 years, ASA physical status I or II, and planned use of neuromuscular blocking agents (NMBAs). Children with neuromuscular diseases unrelated to developmental delay, known allergy to muscle relaxants, significant hepatic, renal, or cardiac dysfunction, those undergoing emergency surgery, or whose guardians refused consent were excluded. Data regarding demographic variables, NMBA dosage, onset of muscle relaxation, neuromuscular monitoring (Train-of-Four count), recovery time, and postoperative complications were recorded. Statistical analysis was performed using SPSS

version 26.0, with quantitative variables compared using an independent sample t-test and categorical variables analyzed using the Chi-square test, considering $p < 0.05$ as statistically significant. Ethical approval was obtained from the Institutional Ethical Review Board, and informed written consent was taken from parents or legal guardians of all participants.

RESULTS

Table 1: Demographic Profile of Study Population (n = 125)

Parameter	TD Group (n = 75)	DD Group (n = 50)	p-value
Age (years), Mean ± SD	6.8 ± 2.4	7.1 ± 2.6	0.412
Male, n (%)	41 (54.7%)	29 (58.0%)	0.701
Female, n (%)	34 (45.3%)	21 (42.0%)	0.701
Weight (kg), Mean ± SD	19.6 ± 5.2	18.4 ± 4.9	0.148

The mean age was 6.8 ± 2.4 years in the TD group and 7.1 ± 2.6 years in the DD group, with no statistically significant difference ($p = 0.412$). In terms of gender, 54.7% of TD children were male compared to 58.0% in the DD group ($p = 0.701$). The mean weight was 19.6 ± 5.2 kg in TD children and 18.4 ± 4.9 kg in DD children ($p = 0.148$), indicating comparable baseline characteristics between groups.

Table 2: Clinical Characteristics of the Developmentally Delayed Group (n = 50)

Diagnosis	Frequency (n)	Percentage (%)
Cerebral Palsy	40	80.0%
Down Syndrome	2	4.0%
Global Developmental Delay	8	16.0%

Among the 50 children with developmental delay, 40 (80.0%) had cerebral palsy, making it the most common diagnosis. 2 (4.0%) had Down syndrome, and 8 (16.0%) had global developmental delay.

Table 3: Muscle Relaxant Dosage and Onset Time Comparison

Parameter	TD Group (n = 75)	DD Group (n = 50)	p-value
NMBA Dose (mg/kg), Mean ± SD	0.12 ± 0.02	0.08 ± 0.04	0.032*
Onset Time (seconds), Mean ± SD	78.4 ± 12.5	95.2 ± 14.8	<0.001*

* Statistically significant

The mean dose of neuromuscular blocking agents (NMBAs) administered was 0.12 ± 0.02 mg/kg in TD children and 0.08 ± 0.04 mg/kg in DD children, with the difference being statistically significant ($p = 0.032$). The onset time for muscle relaxation was significantly prolonged in the DD group (95.2 ± 14.8 seconds) compared to the TD group (78.4 ± 12.5 seconds) with a highly significant p-value ($p < 0.001$).

Table 4: Neuromuscular Monitoring (Train-of-Four Responses)

TOF Response at 2 min (Post NMBA)	TD Group (n = 75)	DD Group (n = 50)	p-value
TOF Count 0	64 (85.3%)	47 (94.0%)	0.128
TOF Count 1–2	11 (14.7%)	3 (6.0%)	0.128

At 2 minutes post-NMBA administration, complete neuromuscular blockade (TOF Count 0) was observed in 64 (85.3%) of TD children and 47 (94.0%) of DD children. Partial blockade (TOF Count 1–2) was seen in 11 (14.7%) of TD children and 3 (6.0%) of DD children. Although the DD group showed a trend towards a higher proportion

achieving complete blockade, the difference was not statistically significant (p = 0.128).

Table 5: Recovery Time and Adverse Events

Parameter	TD Group (n = 75)	DD Group (n = 50)	p-value
Recovery Time (min), Mean ± SD	21.5 ± 5.4	28.9 ± 6.7	<0.001*
Prolonged Recovery (>30 min), n (%)	9 (12.0%)	18 (36.0%)	0.001*
Postoperative Respiratory Compromise	2 (2.7%)	5 (10.0%)	0.085

* Statistically significant

The mean recovery time was significantly longer in DD children (28.9 ± 6.7 minutes) compared to TD children (21.5 ± 5.4 minutes, p < 0.001). Prolonged recovery exceeding 30 minutes was observed in 18 (36.0%) of DD children and 9 (12.0%) of TD children, showing a statistically significant difference (p = 0.001). Postoperative respiratory compromise occurred in 5 (10.0%) of DD children compared to 2 (2.7%) in TD children; however, this difference did not reach statistical significance (p = 0.085).

DISCUSSION

The present study highlights significant differences in neuromuscular blocking agent (NMBA) response between typically developing (TD) children and those with developmental delay (DD), a pattern increasingly recognized in pediatric anesthetic practice. Our finding of lower NMBA requirements in the DD group (0.08 ± 0.04 mg/kg) compared to TD children (0.12 ± 0.02 mg/kg) is consistent with prior studies demonstrating increased sensitivity to muscle relaxants in children with neurological impairments. For instance, Lin *et al*. reported that children with cerebral palsy exhibit enhanced sensitivity to rocuronium, potentially due to altered neuromuscular junction physiology, reduced muscle mass, and abnormal muscle tone.[11] Similar observations were made by Meistelman *et al*, who emphasized that the combination of hypotonia and structural neuromuscular changes in DD populations affects both NMBA pharmacokinetics and pharmacodynamics.[12] Our observation of delayed onset of muscle relaxation in DD children (95.2 ± 14.8 seconds vs. 78.4 ± 12.5 seconds in TD; p < 0.001) corroborates the findings of Lee *et al*., who demonstrated that the onset and duration of action of NMBAs are often unpredictable in children with cerebral palsy due to variable drug distribution and receptor sensitivity.[13] Moreover, although not statistically significant, a higher proportion of DD children in our study achieved complete neuromuscular blockade (TOF Count 0 in 94.0% vs. 85.3% in TD), which aligns with Michaleff ZA *et al*.'s report highlighting the difficulties in interpreting neuromuscular monitoring in children with neuromuscular disorders, where exaggerated blockade may occur even with reduced dosing.[14]

A particularly concerning finding was the significantly prolonged recovery time in DD children (28.9 ± 6.7 minutes vs. 21.5 ± 5.4 minutes in TD; p < 0.001), echoing the results of Ye *et al*., who described impaired NMBA metabolism and delayed clearance in pediatric patients with neuromuscular abnormalities.[15] These recovery delays have profound clinical implications, as residual neuromuscular blockade (RNMB) is strongly associated with increased postoperative pulmonary complications, a relationship well-established in the literature. Brull *et al* documented that even minimal residual blockade can compromise airway protection, leading to hypoxia, aspiration, and respiratory events, particularly in vulnerable populations.[16] Our study also observed a higher, though not statistically significant, incidence of postoperative respiratory compromise in DD children (10.0% vs. 2.7% in TD), reinforcing the need for enhanced perioperative vigilance in this group. Furthermore, our findings strongly support the routine use of objective, quantitative neuromuscular monitoring, as advocated by Baillard *et al*, who demonstrated that quantitative TOF monitoring significantly reduces RNMB and associated complications compared to clinical assessment alone.[17, 18] The increased sensitivity to NMBAs, delayed onset, deeper blockade, and prolonged recovery observed in our DD cohort are consistent with the underlying pathophysiological changes associated with developmental delay, including altered muscle fiber composition,

reduced acetylcholine receptor density, and impaired neuromuscular transmission, as described in both pediatric and adult neuromuscular literature.[19] These results highlight the critical importance of individualized anesthetic management, cautious NMBA dosing, and meticulous postoperative monitoring in children with developmental delay to minimize adverse outcomes. Given the rising number of children with developmental disabilities presenting for surgical procedures, as documented by Zablotsky *et al*., optimizing perioperative care through tailored approaches is both a clinical priority and a patient safety imperative.[20]

Limitations of The Study

The study was conducted in a single hospital with a small sample size. So, the results may not represent the whole community.

CONCLUSION

This study demonstrates that children with developmental delay exhibit increased sensitivity to muscle relaxants, delayed onset of neuromuscular blockade, deeper blockade trends, and significantly prolonged recovery compared to typically developing children. These findings highlight the need for individualized anesthetic dosing, routine quantitative neuromuscular monitoring, and extended postoperative observation to enhance safety and optimize muscle relaxation efficacy in this vulnerable pediatric population.

Recommendation

It is recommended that children with developmental delay undergoing procedures requiring muscle relaxation receive individualized NMBA dosing guided by quantitative neuromuscular monitoring, with careful perioperative planning and extended postoperative observation to reduce the risk of prolonged recovery and respiratory complications.

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