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Predictive Performance Of Armitage And Takasaki Formulas In Estimating Local Anesthetic Volume For Pediatric Caudal Block In Lower Abdominal Surgery: A Prospective Comparative Study

Murali Manoj. M[1*], Uma. G[2], Vivekanandh M[3], Muthuselvan.M[4]

[1*]Professor, Dept of Anaesthesiology, Karpaga Vinayaga Institute of Medical Sciences & Research Centre, GST Road, Chinna Kolambakkam, Madhuranthagam Taluk, Chengalpattu District – 603308 Mail ID - mmm.slazenger@gmail.com, ORCID ID – 0000-0002-5109-7610
[2]Associate Professor, Dept of Anaesthesiology, Karpaga Vinayaga Institute of Medical Sciences & Research Centre, GST Road, Chinna Kolambakkam, Madhuranthagam Taluk, Chengalpattu District – 603308, Mail ID - umakumar.jss@gmail.com, ORCID ID – 0000 - 0003 - 4784 - 617X
[3]Senior Resident, Dept of Anaesthesiology, Karpaga Vinayaga Institute of Medical Sciences & Research Centre, GST Road, Chinna Kolambakkam, Madhuranthagam Taluk, Chengalpattu District – 603308, Mail ID - peruvivan1711@gmail.com, ORCID ID – 0000-0001-7204-4908
[4]Senior Resident in Anaesthesiology (Trauma care) Department of Emergency Medicine, Government Vellore medical College, Vellore- 632011, Mail ID - 9043132098m@gmail.com, ORCID ID – 0000-0003-1385- 9052

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ABSTRACT

Background: Caudal epidural anesthesia is a widely used technique for pediatric lower abdominal surgeries. However, there is no universal consensus on the optimal formula for estimating local anesthetic (LA) volume. The Armitage formula, though well-established, may lead to overestimation, while the Takasaki modification introduces age- and weight-adjusted dosing aimed at minimizing potential toxicity. This study evaluates the predictive performance of both formulas in pediatric caudal blocks.

Methods: This prospective, randomized, comparative observational study was conducted over six months in the Department of Anaesthesiology at Karpaga Vinayaga Institute of Medical Sciences & Research Centre. Sixty children aged 6 months to 8 years undergoing elective lower abdominal surgeries were randomized into two groups of 30 each. Group A received LA volume as per the Armitage formula (1 mL/kg to T10), while Group T received volume calculated by the Takasaki formula (weight × [0.07 + 0.002 × age in months]). All blocks were administered with 0.25% bupivacaine following standard anesthesia protocols.

Results: Demographic characteristics were comparable between the two groups ($p > 0.05$). Group A (Armitage) demonstrated significantly faster onset (6.4 ± 1.3 vs. 8.1 ± 1.5 min, $p < 0.01$), longer duration of analgesia (345 ± 32 vs. 290 ± 35 min, $p < 0.01$), and fewer patients requiring rescue analgesia (3/30 vs. 9/30, $p = 0.04$). However, Group T (Takasaki group) used significantly lower volumes of LA (8.5 ± 0.9 vs. 10.2 ± 1.1 mL, $p < 0.001$). Adverse effects were minimal and statistically insignificant in both groups.

Conclusion: The Armitage formula yielded superior block characteristics, while the Takasaki method reduced anesthetic volume, potentially enhancing safety in younger children. Both methods were safe. Formula selection should be tailored to patient age, weight, and clinical context to balance efficacy and safety in pediatric caudal anesthesia.

Keywords: Pediatric caudal anesthesia, Armitage formula, Takasaki formula, Local anesthetic volume, Analgesia duration.

INTRODUCTION

The management of perioperative pain in pediatric patients presents unique challenges due to the physiological and anatomical differences compared to adults. Among various regional anesthesia techniques, caudal epidural anesthesia has gained prominence as a safe, effective, and widely practiced method for providing intraoperative and postoperative analgesia in children undergoing lower abdominal, perineal, and lower limb surgeries. Since its introduction into pediatric practice in the 1930s, caudal block has remained a cornerstone in pediatric regional anesthesia due to its simplicity, predictable spread, and favorable safety profile.

Historically, the volume of local anesthetic used in caudal blocks was determined empirically, often based on the anesthesiologist's clinical experience. This approach led to variability in the extent of analgesia and, in some cases, complications such as high block, motor blockade, or systemic toxicity. To standardize dosing, Armitage [1] proposed a

formula based on the concept of segmental dermatomal spread, recommending 0.1 mL/kg per dermatome of 0.25% bupivacaine, with 1 mL/kg covering approximately T10–S5. While the Armitage formula has remained a reference point for decades, concerns have arisen regarding its tendency to overestimate anesthetic volume in infants and neonates, especially with evolving safety thresholds for local anesthetic systemic toxicity.

To address these limitations, Takasaki and colleagues [2] introduced a modified formula that incorporated patient weight and age to more accurately predict the volume required for caudal blockade, especially in younger children with varying sacral anatomy and cerebrospinal fluid distribution. Their approach aimed to optimize the balance between efficacy and safety by avoiding unnecessary high spread or motor blockade. Recent advancements in imaging, including ultrasound guidance, have further refined our understanding of drug spread in the epidural space and confirmed the variability in caudal anatomy that impacts block success.

A review by Bosenberg et al [3] highlighted the importance of individualized dosing in pediatric neuraxial blocks and underscored the role of age- and weight-based modifications in optimizing block height. Similarly, a randomized trial by Hassan et al [4] comparing conventional and modified dosing strategies for caudal anesthesia found improved accuracy and reduced side effects with tailored volume calculations. These studies emphasize the need for comparative evaluations of existing formulas under standardized clinical conditions.

Despite the availability of various dosing guidelines, there is still no universal consensus on the ideal formula for determining the appropriate volume of local anesthetic for caudal block in children. Moreover, discrepancies between predicted and actual dermatomal spread have been reported, leading to variable analgesic outcomes. Given the critical need for both effective analgesia and safety in pediatric patients, it becomes imperative to systematically compare commonly used formulas such as those proposed by Armitage and Takasaki.

This prospective comparative study aims to evaluate the predictive performance of the Armitage and Takasaki modification formulas in estimating the optimal local anesthetic volume for caudal epidural blocks in pediatric patients undergoing lower abdominal surgeries. By analyzing parameters such as sensory block adequacy, duration of analgesia, and adverse effects, this study seeks to contribute evidence toward refining volume estimation strategies and enhancing the safety profile of pediatric regional anesthesia.

MATERIALS AND METHODS

This study was conducted over six months (June 2024 – December 2024) as a prospective, randomized, comparative observational study in the Operation Theatre Complex, Department of Anaesthesiology, Karpaga Vinayaga Institute of Medical Sciences & Research Centre, following approval from the Institutional Ethics Committee. The study aimed to evaluate and compare the predictive performance of the Armitage and Takasaki modification formulas in estimating the optimal volume of local anesthetic for caudal epidural block in pediatric patients undergoing elective lower abdominal surgeries.

A total of 60 pediatric patients, aged 6 months to 8 years with ASA physical status I or II, scheduled for elective lower abdominal surgeries (e.g., herniotomy, orchidopexy, appendectomy) under general anesthesia with caudal block supplementation, were enrolled in the study. Written informed consent was obtained from the parents or legal guardians of all participants.

Inclusion Criteria:

- Children aged between 6 months and 8 years
- ASA physical status I–II
- Undergoing elective lower abdominal surgeries
- Consent obtained from parents/ legal guardians

Exclusion Criteria:

- Infection at the sacral region or systemic sepsis
- Coagulopathy or bleeding disorders
- Allergy to local anesthetics
- Congenital spinal anomalies or previous spinal surgery
- Neurological disorders

Patients were randomly allocated into two groups of 30 each using a computer-generated randomization table:

- Group A (Armitage Formula Group): Local anesthetic volume calculated using the Armitage formula (1 mL/kg to reach T10 dermatome).

• Group T (Takasaki Formula Group): Volume calculated using Takasaki's modification formula (volume = weight (kg) × [0.07 + 0.002 × age in months]).

All patients were premedicated with oral midazolam (0.5 mg/kg) 30 minutes before surgery. In the operating room, standard monitors (ECG, NIBP, SpO_2) were applied. Anesthesia was induced with sevoflurane in oxygen and maintained with LMA/Endotracheal tube with nitrous oxide, oxygen, and sevoflurane with atracurium based on the type of surgical procedure.
Following induction and securing of the airway, patients were placed in the lateral decubitus position for caudal block. Under aseptic precautions, caudal anesthesia was administered using a 22G short-beveled needle through the sacral hiatus. The calculated volume of 0.25% bupivacaine was injected slowly over 30 seconds after negative aspiration for blood or cerebrospinal fluid.

Parameters Assessed
• Onset of analgesia (time to surgical readiness)
• Duration of analgesia (time to first rescue analgesic postoperatively)
• Need for intraoperative rescue analgesia
• Incidence of adverse effects (e.g., motor block, urinary retention, bradycardia, high block)
Data were recorded and analyzed using SPSS version 25.0. Continuous variables were compared using Student's t-test or the Mann-Whitney U test. Categorical variables were compared using the Chi-square or Fisher's exact test. A p-value of <0.05 was considered statistically significant.

RESULTS
A total of 60 pediatric patients were enrolled and randomized into two groups of 30 each. The demographic variables between the Armitage Group (Group A) and the Takasaki Group (Group T) were comparable, with no statistically significant difference.

TABLE 1: Demographic Characteristics

Parameter	**Group A (Armitage)**	**Group T (Takasaki)**	***p*-value**
Age (years)	4.2 ± 2.3	4.4 ± 2.1	0.71
Weight (kg)	14.8 ± 3.7	15.1 ± 3.5	0.68
Gender (M/F)	18/12	17/13	0.79
ASA Grade I/II	25/5	26/4	0.73

Table 1 - Shows comparable demographic characteristics between the Armitage and Takasaki groups, with no statistically significant differences in age, weight, gender distribution, or ASA grading ($p > 0.05$). This baseline similarity ensures that observed differences in block performance are attributable to the dosing formulas rather than patient variability.

TABLE 2: Caudal Block Characteristics and Outcomes

Outcome Parameter	**Group A (Armitage)**	**Group T (Takasaki)**	***p*-value**
Volume of LA Used (mL)	10.2 ± 1.1	8.5 ± 0.9	<0.001
Onset Time (min)	6.4 ± 1.3	8.1 ± 1.5	<0.01
Duration of Analgesia (min)	345 ± 32	290 ± 35	<0.01
Rescue Analgesia Required (n)	3/30	9/30	0.04
Adverse Effects (any)	2/30	1/30	0.55 (NS)

Table 2 - Indicates that the Armitage formula provides superior clinical efficacy for caudal blocks in pediatric lower abdominal surgeries. It demonstrated a significantly faster onset and prolonged duration of analgesia compared to the Takasaki formula. Additionally, fewer patients in the Armitage group required rescue analgesia, reflecting more effective intraoperative pain control.

Conversely, the Takasaki formula, although slightly less effective in terms of onset and duration, required significantly lower volumes of local anesthetic, which may offer a safety advantage in younger or lower-weight children where systemic toxicity is a concern. Both formulas were found to be safe with minimal adverse effects.

FIGURE 1: Comparative Analysis of Armitage and Takasaki Formulas for Pediatric Caudal Block: Volume, Onset, Analgesia Duration, and Rescue Requirement

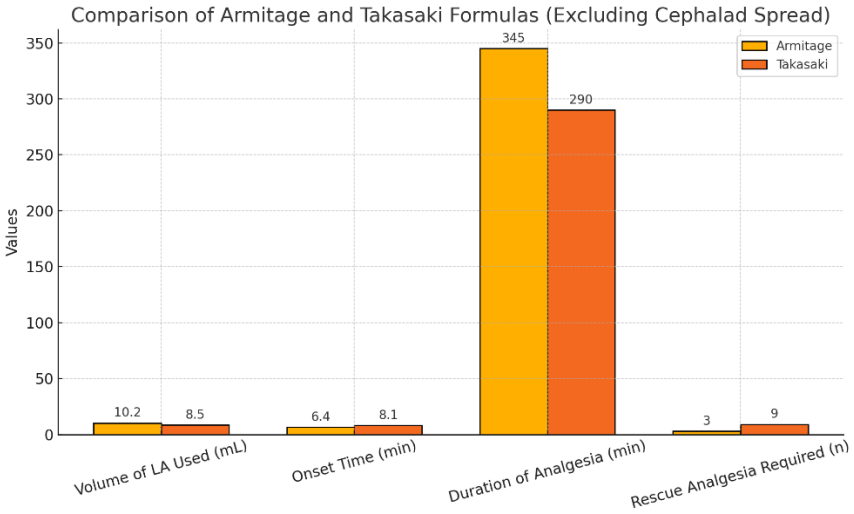

Figure 1 - Comparative analysis of clinical parameters between Armitage and Takasaki formulas for pediatric caudal block. The graph illustrates differences in four key outcome measures: volume of local anesthetic used, onset time of analgesia, duration of postoperative analgesia, and the number of patients requiring intraoperative rescue analgesia. The Armitage formula demonstrated superior performance in onset, duration, and reduced need for rescue analgesia, while the Takasaki formula showed significantly lower local anesthetic volume requirements.

DISCUSSION

The present study compared the predictive performance of the Armitage and Takasaki formulas in estimating local anesthetic volumes for pediatric caudal blocks in lower abdominal surgeries. Both formulas are widely used in clinical practice, but to date, few comparative studies have evaluated their clinical efficacy and safety side by side under standardized conditions. Our findings demonstrate that the Armitage formula, although associated with a higher volume of local anesthetic, provided superior clinical performance in terms of faster onset of anesthesia, longer duration of postoperative analgesia, and a lower need for intraoperative rescue analgesics. These outcomes suggest a more reliable and consistent sensory blockade with the Armitage dosing strategy.

Our observations correlate well with previous work by Bosenberg (2020) and Lönnqvist (2021), who emphasized the value of weight-based caudal dosing for achieving effective and reproducible sensory levels in pediatric patients undergoing infraumbilical surgeries [3,5].

In contrast, the Takasaki modification formula, designed to reduce anesthetic volume using an age- and weight-adjusted calculation, resulted in a significantly lower volume of drug administration in our study. While this was associated with slightly less favorable block characteristics, it may present an advantage in specific subgroups such as neonates and infants, where drug toxicity thresholds are more easily exceeded. This potential benefit is consistent with the findings of Fahy et al. (2022) and Kokki et al. (2020), who have advocated for volume-reduction strategies in vulnerable pediatric populations [6,7]. Reducing the total anesthetic dose is particularly important in younger children with lower weight and immature hepatic metabolism, as highlighted by Suresh and Ecoffey (2023) [8].

Despite the effectiveness of the Armitage formula, excessive volumes can potentially lead to unwanted high dermatomal spread, increasing the risk of motor blockade and delayed ambulation. This concern was supported by reports from Whitaker (2021) and Bailey et al. (2022), who found that administering larger volumes in caudal blocks was sometimes associated with unintended side effects, including postoperative urinary retention, extended sensory blocks, and hindered early mobilization [9,10].

Therefore, although the Armitage formula proved more efficacious in our study's outcome measures, the Takasaki method offers the benefit of volume control and potentially reduced systemic side effects, especially in high-risk age groups. This tailored approach is supported by studies like those of Naguib et al. (2022) and Tanaka et al. (2021), who emphasized the importance of age-specific anatomical and pharmacological considerations in neuraxial anesthesia [10,11].

Our study also reinforces conclusions from comparative trials conducted by Hassan et al. (2022), Choudhury et al. (2023), and Yildiz et al. (2021), which collectively support the use of formula-based and individualized dosing strategies rather than empirical or fixed-volume approaches [4,13,14]. The role of ultrasound guidance in caudal anesthesia has been shown to enhance accuracy and reduce variability, as documented by Walker et al. (2023) and Mitra et al. (2020) [15,16]. Lastly, as emphasized by Iliescu et al. (2023), formula selection should not be rigid but instead tailored to the child's age, weight, and specific surgical requirements, striking the best balance between efficacy and safety [17].

CONCLUSION

The Armitage formula, though involving higher anesthetic volumes, demonstrated superior block efficacy in terms of faster onset, longer analgesia, and reduced intraoperative rescue needs compared to the Takasaki formula. However, the Takasaki method's lower volume requirement may offer a safety advantage in younger or low-weight children. Both techniques were clinically safe. Formula selection should therefore be individualized based on patient characteristics to optimize both analgesic effectiveness and anesthetic safety in pediatric caudal blocks.

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