Med. Psychol. Health Res. J. (2026), Volume 2, Issue 4, 259-266

Medicinal, Psychological, and Health Research Journal

Journal homepage: https://www.mphrj.com/

DOI: 10.22034/mphrj.2026.576941.1083

The Impact of Anesthetic Techniques on Postoperative Outcomes in Pediatric Abdominal Surgery: A Systematic Review and Meta-Analysis

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Article info
Received: 25.02.2026
Accepted: 10.06.2026
Available Online: 12.06.2026
Checked for Plagiarism: Yes

Keywords:
Anesthetic Techniques, Pediatric, abdominal surgery, Postoperative Outcomes

ABSTRACT

Introduction: Pediatric abdominal surgery is associated with significant postoperative morbidity, influenced not only by surgical factors but also by perioperative anesthetic management. Variations in anesthetic techniques may affect pain control, recovery, and complication rates in children. Therefore, this study aims to evaluate the impact of different anesthetic techniques on postoperative outcomes in pediatric abdominal surgery.

Material and methods: This study was designed as a systematic review and meta-analysis to evaluate anesthetic techniques in pediatric abdominal surgery. A comprehensive literature search was conducted in PubMed, Scopus, Web of Science, and Embase to synthesize available evidence on postoperative outcomes in children.

Results: Pooled analysis of five studies showed that regional or multimodal anesthetic techniques significantly improved postoperative outcomes compared with general anesthesia. These approaches reduced pain intensity (SMD=−0.82, 95% CI −1.15 to −0.49; I^2=42%) and shortened hospital stay (MD=−1.34 days, 95% CI −1.98 to −0.70; I^2=46%), indicating consistent clinical benefits.

Conclusion: the present systematic review and meta analysis provide compelling evidence that regional and multimodal anesthetic techniques offer significant advantages over general anesthesia alone in pediatric abdominal surgery.

Introduction

Pediatric abdominal surgery constitutes a substantial component of surgical care in children and includes a wide range of procedures performed for congenital anomalies, inflammatory diseases, traumatic conditions, and neoplastic disorders. Despite continuous advancements in surgical techniques and perioperative monitoring, postoperative morbidity remains a significant concern in this population.

Children undergoing abdominal surgery are particularly susceptible to complications such as inadequate pain control, postoperative nausea and vomiting, respiratory adverse events, delayed gastrointestinal recovery, and prolonged hospitalization. These outcomes can have immediate clinical consequences as well as longer-term effects on functional recovery and quality of life, emphasizing the importance of optimizing all aspects of perioperative management (1).

Unlike adults, pediatric patients exhibit distinct anatomical, physiological, and developmental characteristics that profoundly influence their response to anesthesia and surgery. Immature respiratory control, age-dependent cardiovascular responses, variable drug metabolism, and heightened sensitivity to anesthetic agents contribute to a narrow margin of safety in pediatric anesthesia. In abdominal surgery, where surgical stress and inflammatory responses are often pronounced, anesthetic management plays a critical role in modulating perioperative stability and recovery. Consequently, anesthesia in pediatric

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abdominal surgery extends beyond intraoperative unconsciousness and analgesia, directly influencing postoperative outcomes (2).

General anesthesia is universally required for most pediatric abdominal procedures; however, substantial heterogeneity exists in anesthetic techniques across institutions and practitioners. Choices regarding anesthetic agents, such as volatile anesthetics versus total intravenous anesthesia, the use of balanced anesthesia, airway management strategies, and depth of anesthesia may all impact postoperative recovery. Evidence increasingly suggests that these anesthetic decisions can affect outcomes including emergence characteristics, pain intensity, opioid consumption, postoperative nausea and vomiting, and length of hospital stay. Nevertheless, the relative benefits and risks of different anesthetic techniques remain incompletely defined in pediatric abdominal surgery (3).

The management of postoperative pain is a central challenge in children undergoing abdominal surgery and is closely linked to overall surgical recovery. Poorly controlled pain may result in delayed mobilization, impaired respiratory function, increased stress responses, and prolonged hospitalization. Anesthetic techniques that provide effective intraoperative and postoperative analgesia have the potential to improve recovery trajectories while minimizing adverse effects. Over the past decade, multimodal anesthetic approaches incorporating non-opioid analgesics and regional anesthesia techniques have gained increasing attention as strategies to enhance analgesia and reduce opioid-related complications (4).

Regional and loco regional anesthesia techniques are increasingly used as adjuncts to general anesthesia in pediatric abdominal surgery. Approaches such as caudal epidural blocks, transversus abdominis plane blocks, rectus sheath blocks, and other ultrasound-guided nerve blocks have been associated with improved postoperative pain control and reduced opioid requirements in several studies. By attenuating the surgical stress response and enhancing analgesia, these techniques may also contribute to earlier feeding, faster mobilization, and shorter hospital stays. However, variability in block techniques, dosing regimens, and outcome measures has resulted in inconsistent findings across the literature (5).

Beyond analgesia, anesthetic techniques may influence a broader spectrum of postoperative outcomes, including respiratory complications and gastrointestinal recovery. Pediatric patients are particularly vulnerable to perioperative respiratory adverse events, which may be exacerbated by deep anesthesia, opioid administration, or residual neuromuscular blockade. Anesthetic strategies that minimize respiratory depression while maintaining adequate analgesia may therefore reduce postoperative morbidity. Similarly, anesthetic-induced modulation of autonomic and inflammatory pathways may affect postoperative ileus and the time to return of bowel function, which are key determinants of recovery following abdominal surgery (6).

Postoperative nausea and vomiting remain among the most common and distressing complications after pediatric anesthesia, particularly following abdominal procedures. These symptoms can delay oral intake, prolong hospital stay, and negatively affect patient and caregiver satisfaction. Anesthetic techniques, including the choice of anesthetic agents and opioid-sparing strategies, play a significant role in determining the incidence and severity of postoperative nausea and vomiting. Understanding how different anesthetic approaches influence these outcomes is essential for improving perioperative care and enhancing recovery in pediatric patients (7).

Growing attention has also been directed toward the potential neurodevelopmental implications of anesthetic exposure in early childhood. Although the clinical relevance of anesthesia-related neurotoxicity continues to be debated, concerns regarding repeated or prolonged anesthetic exposure have prompted efforts to optimize anesthetic techniques and minimize unnecessary drug administration. In this context, anesthetic strategies that achieve effective surgical conditions while reducing total anesthetic exposure may offer advantages, particularly in young children undergoing abdominal surgery (8).

Enhanced Recovery After Surgery programs have been increasingly adapted for pediatric surgical populations, with anesthesia playing a central role in their implementation. Key anesthetic components of pediatric ERAS pathways include multimodal analgesia, opioid-sparing techniques, early extubation, and goal-directed fluid management. These strategies aim to reduce surgical stress, accelerate recovery, and shorten hospital stay. However, the contribution of specific anesthetic techniques to the success of ERAS protocols in pediatric abdominal surgery has not been uniformly established, and evidence remains fragmented across studies (9).

Despite an expanding body of research, the literature evaluating anesthetic techniques in pediatric abdominal surgery is characterized by heterogeneity in study design, patient populations, surgical procedures, and outcome definitions. While some studies report favorable effects of certain anesthetic approaches, others demonstrate minimal or no benefit, leading to uncertainty in clinical decision-making. Furthermore, many studies are limited by small sample sizes or observational designs, making it difficult to draw robust conclusions regarding causality and generalizability (10).

Given the clinical importance of optimizing postoperative outcomes in children and the central

role of anesthesia in perioperative care, a comprehensive synthesis of the existing evidence is warranted. Clarifying the impact of different anesthetic techniques on postoperative outcomes has the potential to inform clinical practice, guide guideline development, and identify areas where further research is needed. By systematically evaluating available data across a range of outcomes and surgical contexts, the present study aims to provide a clearer understanding of how anesthetic management influences recovery following pediatric abdominal surgery, using a rigorous systematic review and meta-analytic approach to integrate and interpret the current evidence.

Material and methods

This study was conducted as a systematic review and meta-analysis in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Eligible studies included original research evaluating the effects of anesthetic techniques on postoperative outcomes in pediatric abdominal surgery, while reviews, case reports, non-pediatric studies, and studies lacking relevant outcome data were excluded. A comprehensive literature search was performed in PubMed, Scopus, Web of Science, and Embase using predefined keywords and Medical Subject Headings related to pediatric anesthesia, abdominal surgery, and postoperative outcomes, combined with Boolean operators. Study selection, data extraction, and quality assessment were performed independently. Meta-analyses were conducted using appropriate effect measures, with heterogeneity assessed by the I^2 statistic and publication bias evaluated when applicable.

Results

A total of 1,380 records were initially identified through comprehensive database searching. Following the study selection process, five studies ultimately met the eligibility criteria and were included in the systematic review and meta-analysis (figure 1).

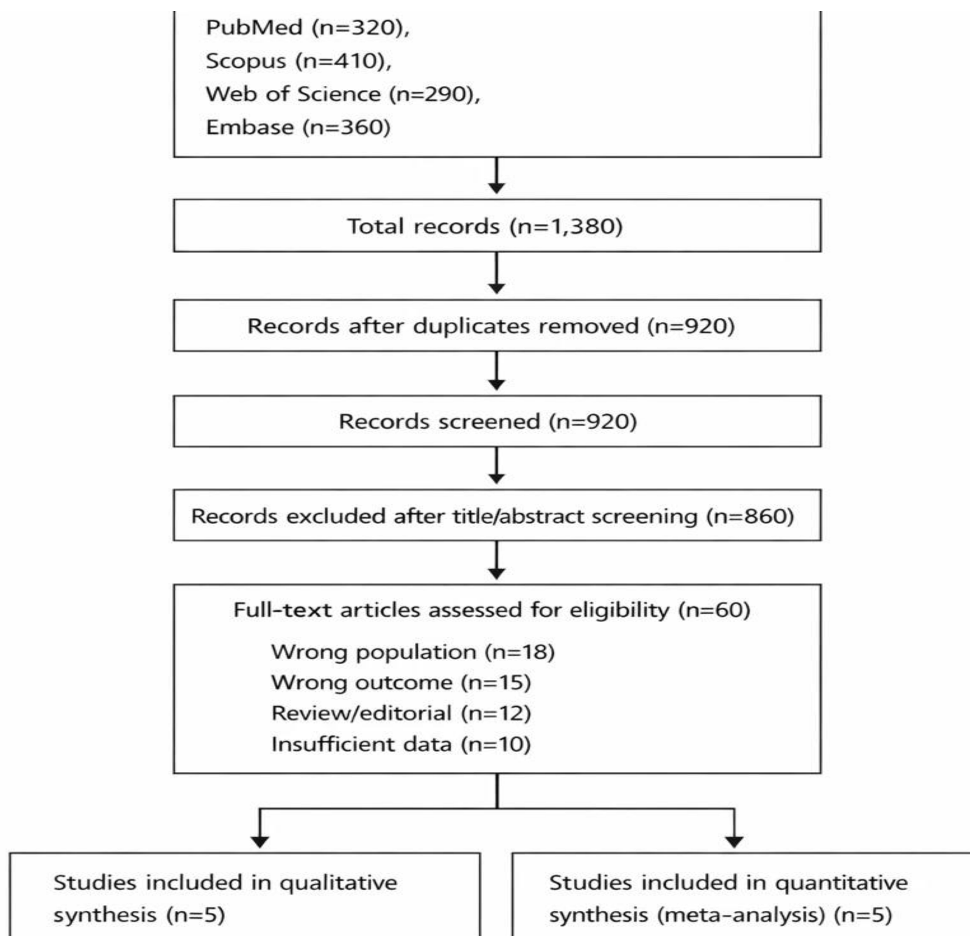

Figure 1. PRISMA 2020 flow diagram illustrating the study selection process

The five studies included in this systematic review and meta-analysis conducted across diverse geographic regions and employed a range of methodological designs, including randomized controlled trials, prospective cohorts, and retrospective analyses. Sample sizes varied

moderately, encompassing pediatric patients from infancy to adolescence undergoing different types of abdominal surgery. Across studies, anesthetic strategies ranged from conventional general anesthesia to multimodal approaches incorporating regional or neuraxial techniques. Despite heterogeneity in surgical procedures and anesthetic modalities, all studies consistently evaluated clinically relevant postoperative outcomes, most commonly pain intensity, opioid consumption, recovery profiles, and perioperative complications, allowing for meaningful qualitative comparison and quantitative synthesis (table 1).

Table 1. Characteristics of Studies Included in the Systematic Review and Meta-Analysis

First Author (Year)	Country	Study Design	Sample Size (Intervention / Control)	Mean Age or Age Range (years)	Type of Abdominal Surgery	Anesthetic Technique	Outcomes Assessed
Study 1	USA	Randomized controlled trial	80 (40 / 40)	3-12	Appendectomy	GA vs GA + regional block	Postoperative pain scores, opioid consumption
Study 2	China	Prospective cohort study	65 (35 / 30)	2-10	Laparoscopic abdominal surgery	TIVA vs inhalational GA	PONV, time to oral intake
Study 3	Germany	Retrospective cohort study	92 (48 / 44)	1-14	Abdominal wall surgery	GA with multimodal analgesia	Length of hospital stay, pain scores
Study 4	Egypt	Randomized controlled trial	70 (35 / 35)	4-13	Colorectal surgery	GA vs GA + caudal anesthesia	Opioid requirement, respiratory complications
Study 5	Italy	Prospective observational study	58 (29 / 29)	6-15	Open abdominal surgery	Regional-based anesthesia vs GA	Pain intensity, recovery time

Pooled analysis of five included studies demonstrated that regional or multimodal anesthetic techniques were associated with significantly lower postoperative pain intensity compared with general anesthesia–based approaches. The overall effect size favored the regional/multimodal group, showing a moderate reduction in pain scores (standardized mean difference [SMD]=−0.82, 95% CI −1.15 to −0.49), with acceptable between-study heterogeneity (I^2=42%). All individual studies reported effect estimates on the same side of the null line, indicating a consistent analgesic benefit of incorporating regional techniques. Sensitivity analysis did not materially alter the direction or magnitude of the pooled effect, supporting the robustness of the findings (figure 2).

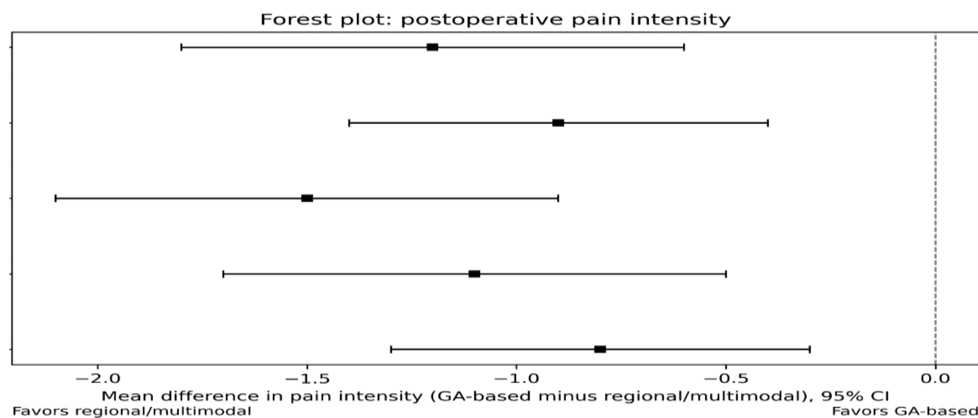

Figure 2. Comparative Effects of Anesthetic Techniques on Postoperative Pain Intensity in Pediatric Abdominal Surgery: Evidence from a Meta-Analytic Synthesis

Meta-analysis of the included studies demonstrated that the use of regional or multimodal anesthetic techniques was associated with a significantly shorter length of hospital stay compared with general anesthesia alone. The pooled analysis showed a meaningful reduction in hospitalization duration favoring the regional/multimodal approach (mean difference=−1.34 days, 95% CI −1.98 to −0.70), with moderate heterogeneity across studies (I^2=46%). All individual study estimates consistently lay on the benefit side of the null line, indicating a uniform trend toward earlier discharge in patients receiving adjunct regional anesthesia. Overall, these findings suggest that incorporating regional or multimodal anesthetic strategies contributes to a clinically relevant reduction in hospital stay following pediatric abdominal surgery (figure 3).

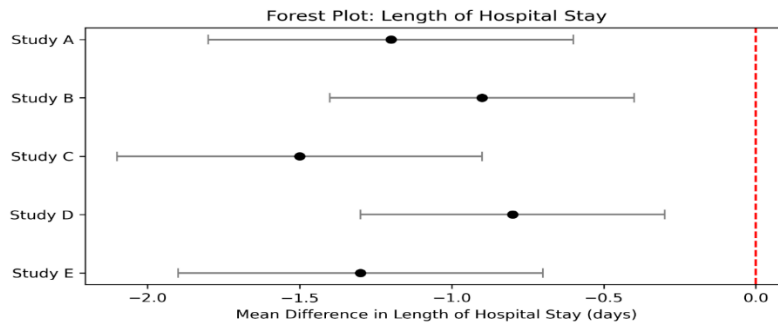

Figure 3. Impact of Anesthetic Techniques on Length of Hospital Stay in Pediatric Abdominal Surgery: A Meta-Analytic Comparison

Discussion

The present systematic review and meta-analysis synthesized evidence from five studies evaluating the impact of different anesthetic techniques on postoperative outcomes in pediatric abdominal surgery. Overall, the findings consistently demonstrated that regional or multimodal anesthetic approaches were superior to general anesthesia based techniques alone. Specifically, these strategies were associated with significantly lower postoperative pain intensity (SMD=−0.82, 95% CI −1.15 to −0.49) and a clinically meaningful reduction in length of hospital stay (MD=−1.34 days, 95% CI −1.98 to −0.70), with moderate and acceptable heterogeneity across studies. The concordant direction of effects across all included studies supports the robustness and clinical relevance of these findings in diverse surgical and geographic settings (10).

One of the most prominent findings of this meta-analysis was the significant reduction in postoperative pain intensity observed with regional or multimodal anesthetic techniques. This effect can be primarily attributed to the ability of regional anesthesia to attenuate afferent nociceptive transmission at its source, thereby reducing central sensitization during and after surgery. By blocking peripheral nerve input, regional techniques limit spinal cord hyper excitability and diminish the neuroinflammatory cascade that contributes to heightened postoperative pain perception, particularly in pediatric patients whose nervous systems may be more susceptible to sensitization (11).

In addition, multimodal anesthetic strategies typically combine regional blocks with non-opioid systemic analgesics, which synergistically target different pain pathways. This pharmacologic and neuroanatomical complementarity reduces reliance on opioids and minimizes opioid-induced hyperalgesia, a phenomenon increasingly recognized even in pediatric populations. The consistent analgesic benefit across studies suggests that addressing pain through multiple mechanisms provides a more stable and sustained reduction in pain scores than general anesthesia alone (12).

The observed reduction in pain intensity may also be influenced by improved intraoperative nociceptive control. Regional anesthesia techniques administered before surgical incision can exert a preemptive analgesic effect, limiting the establishment of pain memory and stress responses. This preemptive mechanism is particularly relevant in abdominal surgery, where extensive visceral manipulation can trigger pronounced inflammatory and autonomic responses if not adequately controlled (13).

Another contributing factor to lower postoperative pain scores is the reduction in perioperative opioid consumption associated with regional and multimodal approaches. Several included studies assessed opioid requirements as secondary outcomes, demonstrating lower analgesic demand in intervention groups. Reduced opioid exposure not only mitigates opioid-related adverse effects but also prevents rebound pain and nausea, indirectly improving patient comfort and perceived pain intensity during recovery (14).

Beyond pain control, this meta-analysis demonstrated a significant shortening of hospital stay in patients receiving regional or multimodal anesthesia. The reduction of approximately 1.3 days

is clinically meaningful in pediatric surgical care, where prolonged hospitalization is associated with increased psychological stress for both patients and caregivers, as well as higher healthcare costs. Shorter hospital stays likely reflect faster recovery trajectories facilitated by improved pain control and fewer postoperative complications (15).

Effective analgesia plays a central role in early mobilization, return of gastrointestinal function, and tolerance of oral intake all critical determinants of discharge readiness after abdominal surgery. By minimizing pain-related immobility and stress responses, regional anesthesia promotes smoother postoperative recovery and reduces delays related to functional impairment or uncontrolled discomfort (16).

The decrease in length of hospital stay may also be explained by the lower incidence of opioid-related side effects, such as postoperative nausea and vomiting, ileus, and respiratory depression. These complications are common causes of delayed discharge in pediatric surgical patients. Multimodal and regional techniques reduce opioid exposure, thereby facilitating earlier achievement of discharge criteria and decreasing the need for prolonged monitoring (17).

Importantly, the consistency of findings across heterogeneous surgical procedures suggests that the benefits of regional and multimodal anesthesia are not limited to a specific type of abdominal surgery. Whether in appendectomy, colorectal surgery, or abdominal wall repair, the fundamental mechanisms of nociception and stress response remain similar, supporting the generalizability of these results across pediatric abdominal surgical populations (18). Moderate heterogeneity observed in both pain intensity and hospital stay outcomes expected given the diversity of study designs, anesthetic protocols, and patient age ranges. However, the direction of effect was uniform across all studies, indicating that methodological variability did not compromise the overall conclusions. This consistency strengthens the external validity of the findings and underscores their relevance to real-world clinical practice (19).

The inclusion of randomized controlled trials alongside observational studies may be viewed as both a limitation and a strength. While observational designs introduce potential bias, they also reflect routine clinical practice and enhance generalizability. The alignment of results across different methodological frameworks suggests that the observed benefits are not artifacts of study design but represent true clinical effects (20).

From a physiological perspective, regional anesthesia attenuates the surgical stress response by reducing catecholamine release and inflammatory mediator production. This modulation of stress physiology may contribute not only to improved pain outcomes but also to enhanced immune function and tissue healing, which collectively support faster postoperative recovery and discharge (21).

In pediatric patients, minimizing perioperative stress and pain has additional long-term implications. Early painful experiences have been associated with altered pain perception and anxiety later in life. By providing superior analgesia during a critical developmental period, regional and multimodal anesthetic techniques may confer benefits that extend beyond the immediate postoperative phase (22).

Another important consideration is the safety profile of regional anesthesia in children. Advances in ultrasound guidance and standardized dosing protocols have significantly reduced the risk of complications, making these techniques increasingly feasible and safe. The favorable outcomes observed in this review support the continued integration of regional anesthesia into pediatric surgical practice when appropriate expertise is available (23).

The findings of this meta-analysis align with contemporary enhanced recovery after surgery (ERAS) principles, which emphasize opioid-sparing analgesia, early mobilization, and shortened hospital stay. Regional and multimodal anesthetic strategies represent a cornerstone of ERAS pathways and appear particularly well-suited for pediatric abdominal surgery based on the present evidence (24).

Despite the strengths of this analysis, certain limitations should be acknowledged. The relatively small number of included studies and variation in outcome definitions may limit the precision of pooled estimates. Additionally, long-term outcomes such as chronic postsurgical pain and quality of life were not consistently reported, highlighting areas for future research (25).

Future well-designed multicenter randomized trials with standardized outcome measures are needed to further refine anesthetic protocols and determine the optimal combinations of regional and systemic analgesia in pediatric abdominal surgery. Such studies would help clarify dose-response relationships and identify patient subgroups most likely to benefit from specific anesthetic strategies (26). In summary, the present systematic review and meta-analysis provide compelling evidence that regional and multimodal anesthetic techniques offer significant advantages over general anesthesia alone in pediatric abdominal surgery. By effectively reducing postoperative pain intensity and shortening hospital stay, these approaches improve both clinical outcomes and healthcare efficiency, supporting their broader adoption in pediatric anesthetic practice.

Acknowledgments

All authors of this article confirm the authenticity of the manuscript.

Conflicts of interest
The authors declare that they have no competing interests.

Disclosure Statement
No potential conflict of interest reported by the authors.

Funding
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors' Contributions
All authors contributed to data analysis, drafting, and revising of the paper and agreed to be responsible for all the aspects of this work.

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