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REVIEW ARTICLE

ADVANCES IN ANESTHESIOLOGY APPLIED DURING THE SURGICAL SCOLIOSIS CORRECTION. A NARRATIVE REVIEW

POSTĘPY W ANESTEZJOLOGII STOSOWANEJ PODCZAS CHIRURGICZNEJ KOREKCJI SKOLIOZY. PRZEGLĄD NARRACYJNY

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ABSTRACT
Scoliosis surgery, particularly in adolescent idiopathic scoliosis, necessitates careful anesthetic management to optimize surgical outcomes and minimize neurophysiological compromise. Neurophysiological compromise refers to the potential disruption of somatosensory-evoked potentials (SSEPs) and motor-evoked potentials (MEPs) during surgery, which are critical indicators of spinal cord integrity. Preserving these signals is essential to reduce the risk of intraoperative neurological injury, such as motor or sensory deficits. This narrative review presents current anesthetic techniques, focusing on Total Intravenous Anesthesia (TIVA) and inhalational methods and their implications for intraoperative neurophysiological monitoring and postoperative recovery. TIVA, utilizing agents like propofol and remifentanil, has emerged as a preferred approach due to its favourable pharmacodynamics, resulting in less suppression of SSEPs and MEPs than inhalational agents. The review highlights the potential of adjuncts, including dexmedetomidine and low-dose ketamine, in enhancing analgesia and mitigating opioid-related side effects.

Furthermore, the erector spinae plane (ESP) block is discussed as an innovative regional technique that may improve postoperative pain control while reducing systemic opioid requirements. Emphasizing a multimodal analgesic strategy, the review underscores the importance of integrating various pharmacological and non-pharmacological approaches to optimize postoperative pain management. Ongoing research is vital for refining anesthetic protocols and enhancing patient outcomes in scoliosis surgery, ultimately ensuring the safety and efficacy of these complex procedures.

Keywords: surgery, anaesthesia, scoliosis

STRESZCZENIE
Operacja skoliozy, szczególnie w przypadku młodzieńczej skoliozy idiopatycznej, wymaga starannego zarządzania anestezjologicznego w celu optymalizacji wyników chirurgicznych i minimalizacji ryzyka uszkodzenia neurofizjologicznego. Niniejszy przegląd narracyjny analizuje aktualne techniki anestezji, koncentrując się na całkowitej anestezji dożylnej (TIVA) oraz metodach wziewnych i ich wpływie na śródoperacyjne monitorowanie neurofizjologiczne oraz powrót do zdrowia po operacji. TIVA, z wykorzystaniem takich leków jak propofol i remifentanyl, zyskała na popularności ze względu na korzystne działanie farmakodynamiczne, które skutkuje mniejszym hamowaniem potencjałów wywołanych somatosensorycznych i motorycznych w porównaniu z lekami wziewnymi. Przegląd podkreśla również potencjał

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adiuwantów, takich jak deksmedetomidyna i ketamina w małych dawkach, w poprawie analgezji i redukcji działań niepożądanych związanych z opioidami. Ponadto, omawiany jest blok płaszczyzny mięśnia prostownika grzbietu (ESP) jako innowacyjna technika regionalna, która może poprawić kontrolę bólu pooperacyjnego, zmniejszając jednocześnie zapotrzebowanie na opioidy systemowe. Zwracając uwagę na strategię multimodalnego zarządzania bólem, przegląd podkreśla znaczenie integracji różnych podejść farmakologicznych i niefarmakologicznych w celu optymalizacji leczenia bólu pooperacyjnego. Kontynuacja badań jest kluczowa dla dalszego doskonalenia protokołów anestezjologicznych oraz poprawy wyników leczenia pacjentów poddawanych operacji skoliozy, zapewniając ostatecznie bezpieczeństwo i skuteczność tych złożonych zabiegów.

Słowa kluczowe: znieczulenie, chirurgia, skolioza

Introduction

Scoliosis surgery, particularly in adolescent idiopathic scoliosis, is a complex procedure to correct abnormal spinal curvature while preserving or improving spinal cord function (Antolovich *et al.,* 2022). Given the intricate relationship between anesthetic techniques and neurophysiological outcomes, the selection of anesthesia is critical for optimizing surgical success and patient safety (Domagalska *et al.,* 2023). The dual objectives of providing adequate analgesia while minimizing the potential for neurophysiological compromise necessitate a thorough understanding of the anesthetic agents and techniques available (Antolovich *et al.,* 2022). Neurophysiological compromise in the context of scoliosis surgery refers to the potential disruption of intraoperative neurophysiological monitoring signals, such as somatosensory-evoked potentials (SSEPs) and motor-evoked potentials (MEPs), which are critical for assessing spinal cord integrity during surgery (Rao *et al.,* 2021). Specific anesthetic agents can suppress or alter these signals, making detecting intraoperative neurological injury in real-time challenging (Grasso *et al.,* 2021). For instance, inhalational anesthetics and high doses of specific intravenous agents may significantly diminish the amplitude or prolong the latency of these signals, increasing the risk of missing subtle signs of spinal cord compromise (Ma *et al.,* 2023). Therefore, anesthetic strategies must balance providing effective pain relief and hemodynamic stability while preserving the reliability of neurophysiological monitoring to ensure patient safety. This review examines the current landscape of anesthetic practices in scoliosis surgery, emphasizing their implications for intraoperative monitoring, recovery, and postoperative pain management (Chmielewska *et al.,* 2020).

Anesthetic Techniques

1. Total Intravenous Anesthesia (TIVA)

Total intravenous anesthesia (TIVA), commonly employing agents such as propofol and remifentanil, has become increasingly favored in scoliosis surgeries due to its favorable pharmacodynamic properties (Petre *et al.,* 2021). Propofol, an alkyl phenol derivative, is known for its rapid onset and short duration of action, making it ideal for maintaining a stable anesthesia depth. Studies indicate that TIVA leads to less suppression of somatosensory evoked potentials (SSEPs) and motor-evoked potentials (MEPs) compared to inhalational agents, particularly nitrous oxide, which has been s, shown to impair alpha motor neuron excitability significantly (Deguchi *et al.,* 2021).

When combined with remifentanil, propofol facilitates rapid recovery and minimizes dose-dependent alterations in neurophysiological monitoring. It provides a reliable platform for continuous assessment of spinal cord function during surgery (Yang *et al.*, 2022).

Research indicates that TIVA results in a lower incidence of intraoperative hypotension and enhances recovery profiles, allowing for quicker emergence from anesthesia and improved neurological assessments in the postoperative period.

2. Inhalational Anesthesia

Inhalational anesthetics, including halogenated agents (e.g., sevoflurane and isoflurane) and nitrous oxide, remain widely used in various surgical settings; however, their application in scoliosis surgery is contentious due to their neurophysiological effects (Li *et al.*, 2020). Inhaled anesthetics are known to produce dose-dependent reductions in MEP amplitudes, raising concerns about their suitability in procedures requiring meticulous spinal cord integrity monitoring. Nitrous oxide has been implicated in impairing neuromuscular transmission and alpha motor neuron excitability, leading to significant reductions in MEP recordings (Badenes *et al.*, 2021).

Although inhalational anesthesia offers advantages in terms of ease of administration and rapid titration, its potential to disrupt neurophysiological monitoring necessitates careful consideration, particularly in surgeries where spinal cord integrity is paramount.

3. Combination Approaches

Combining various anesthetic techniques can enhance outcomes in scoliosis surgery. For instance, adjuncts such as dexmedetomidine, an alpha-2 adrenergic agonist, can be utilized for sedation and analgesia without causing respiratory depression (Walker *et al.*, 2020). Dexmedetomidine has been shown to improve conditions for intraoperative neurophysiological monitoring while maintaining hemodynamic stability (Pacreu *et al.*, 2021). Moreover, the intraoperative infusion of low-dose ketamine, an N-methyl-D-aspartate (NMDA) receptor antagonist, has been suggested to attenuate remifentanil-induced hyperalgesia and opioid tolerance, thereby reducing postoperative opioid requirements (Walker *et al.*, 2020).

4. Erector Spinae Plane Block

The erector spinae plane (ESP) block is an emerging regional anesthesia technique that has gained attention in the context of thoracic and lumbar surgeries, including scoliosis correction (Domagalska *et al.*, 2023). This block involves injecting a local anesthetic into the plane between the erector spinae muscle and the vertebral fascia, providing analgesia to the dermatomes supplied by the spinal nerves (Domagalska *et al.*, 2024). The ESP block exerts its effect through molecular and biochemical mechanisms. By delivering local anesthetics into the fascial plane deep to the erector spinae muscle, the block results in the diffusion of the anesthetic agent to paravertebral spaces, affecting both the dorsal and ventral rami of spinal nerves (Holland *et al.*, 2022; Apaydın Abstracts of the 20th Congress of the IFAA). This action inhibits sodium ion channels on neuronal membranes, preventing depolarization and subsequent transmission of pain signals (Chin *et al.*, 2021). Additionally, the ESP block may reduce local inflammation by stabilizing mast cells and decreasing the release of pro-inflammatory mediators like histamine and cytokines (Domagalska *et al.*, 2024, Jinn *et al.*, 2021; Liu *et al.*, 2021; Tantri *et al.*, 2023). This dual mechanism contributes to adequate analgesia and mitigating the neuroinflammatory response, enhancing postoperative recovery (Reysner *et al.*, 2024).

The ESP block has shown promise in reducing postoperative pain and opioid consumption in patients undergoing various thoracic and abdominal procedures (Domagalska *et al.*, 2023b). Preliminary studies indicate that the ESP block can enhance analgesic efficacy while minimizing the need for systemic opioids, which may help mitigate the risks of opioid-related side effects and hyperalgesia (Domagalska *et al.*, 2024). Additionally, its application in scoliosis surgery may improve intraoperative conditions by allowing for better patient positioning and minimizing intraoperative movement, thereby supporting effective neurophysiological monitoring.

Neurophysiological monitoring

Intraoperative neurophysiological monitoring is essential in scoliosis surgery to detect potential spinal cord ischemia or injury (Daroszewski *et al.,* 2023). SSEPs and MEPs are the primary modalities for evaluating spinal cord function and integrity (Daroszewski *et al.,* 2023b). The anesthetic technique can significantly influence these recordings, with TIVA often yielding more stable results than inhalational agents (Thakkar *et al.,* 2023). Maintaining SSEP and MEP amplitudes within acceptable limits is crucial for real-time assessments of spinal cord status (Castellanos *et al.,* 2020). If significant changes in neurophysiological signals are observed, the ability to perform rapid wake-up tests is essential for validating these findings and making timely surgical adjustments if necessary.

Recovery profiles

The recovery profile from anesthesia is critical to scoliosis surgery, influencing both immediate postoperative outcomes and long-term recovery (Rao *et al.,* 2021). Compared to inhalational agents, TIVA is associated with faster recovery times, a quicker onset of spontaneous ventilation, and earlier neurological assessments (Grasso *et al.*, 2021). Studies have demonstrated that patients receiving TIVA require less time to return to baseline neurologic function, facilitating optimal conditions for postoperative monitoring and evaluation of spinal cord integrity (Spitzer *et al.*, 2022).

In contrast, inhalational anesthetics can prolong recovery times, delaying the return of motor function and potentially complicating postoperative assessments (Kawaguchi *et al.,* 2020). A rapid recovery is particularly beneficial for patients undergoing neurophysiological monitoring, as it allows for timely evaluation of spinal cord function post-surgery (Tanaka *et al.*, 2024).

Postoperative pain management

Effective postoperative pain management is paramount in enhancing recovery and minimizing complications following scoliosis surgery (Lee *et al.,* 2020). A multimodal analgesic approach, integrating . Various pharmacological and non-pharmacological strategies to address pain from multiple pathways are increasingly regarded as the best practice (Collins *et al.,* 2015).

1. Opioid Use and Alternatives

Opioids remain a cornerstone of postoperative pain management; however, their associated side effects, including respiratory depression, constipation, and potential for addiction, highlight the need for alternative analgesic strategies (Shah *et al.,* 2020). The administration of gabapentin, an anticonvulsant agent with analgesic properties, pre- and postoperatively, has been shown to significantly reduce opioid consumption and improve pain scores in patients undergoing scoliosis surgery (Anderson *et al.,* 2020). Additionally, intravenous acetaminophen is effective in enhancing analgesia while minimizing the adverse effects commonly associated with NSAIDs and opioids (Murdock *et al.,* 2023).

2. Regional Anesthesia

Regional anesthesia techniques, including epidural and intrathecal analgesia, have shown promise in providing effective postoperative pain relief while reducing systemic opioid exposure (Setijanto *et al.*). Evidence suggests that epidural analgesia, particularly with local anesthetics or a combination of local anesthetics and opioids, can significantly improve postoperative pain control and enhance patient satisfaction (Chin *et al.,* 2017). However, the efficacy of these techniques remains a subject of debate, as some studies have reported no significant differences in outcomes compared to systemic analgesia alone.

The incorporation of the ESP block into postoperative pain management protocols may further improve outcomes by reducing the reliance on systemic opioids and enhancing overall patient satisfaction (Domagalska *et al.*, 2024; Domagalska *et al.*, 2023). The ESP block offers several advantages in avoiding deep anesthesia during scoliosis

surgery. By providing adequate regional analgesia, the ESB reduces the reliance on high doses of systemic opioids and general anesthetic agents, which are often required to achieve adequate pain control (Domagalska *et al.,* 2023). This allows for lighter planes of anesthesia, preserving the integrity of intraoperative neurophysiological monitoring signals, such as SSEPs and MEPs, critical for detecting spinal cord function during scoliosis surgery (Domagalska *et al.*, 2024). Moreover, the ESP block's opioid-sparing effect minimizes the risk of respiratory depression and hemodynamic instability, ensuring smoother perioperative management (Jinn *et al.,* 2021).

Feedback from surgeons regarding the use of ESP block has mainly been positive. Many reports that lighter anesthesia facilitates more precise and more stable neuromonitoring recordings, which enhances surgical precision and safety (Domagalska *et al.,* 2024). Surgeons also appreciate the reduction in postoperative opioid-related complications, such as nausea, sedation, and delayed recovery, which allows for improved patient outcomes and faster mobilization (Fung *et al.,* 2023). These advantages make ESP block a valuable component of multimodal analgesia in scoliosis surgery, aligning well with both anesthetic and surgical goals.

Conclusion

Anesthesia for scoliosis surgery encompasses diverse techniques, each with unique implications for intraoperative monitoring and postoperative recovery. TIVA is increasingly favored for its stability in neurophysiological monitoring and rapid recovery profiles. At the same time, inhalational agents are approached with caution due to their potential adverse effects on spinal cord function. A multimodal approach to postoperative analgesia is essential for effective pain management, focusing on reducing opioid use and enhancing patient outcomes. The application of regional techniques, such as the erector spinae plane block, holds promise for further improving postoperative pain control and reducing systemic opioid consumption.

As our understanding of the interaction between anesthesia and spinal cord function evolves, ongoing research is crucial for optimizing anesthetic practices in scoliosis surgery. Future studies should aim to elucidate the most effective anesthetic regimens, assess long-term outcomes, and explore novel adjunctive therapies that enhance analgesia while minimizing adverse effects. This comprehensive understanding will ultimately improve care and outcomes for patients undergoing scoliosis correction procedures.

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